

**UNITED STATES DISTRICT COURT  
FOR THE DISTRICT OF DELAWARE**

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AUTOMOTIVE TECHNOLOGIES  
INTERNATIONAL, INC.,

C.A. No. 06-187-GMS

Plaintiff,  
vs.

AMERICAN HONDA MOTOR COMPANY,  
ELESYS NORTH AMERICA, INC., and  
GENERAL MOTORS CORPORATION,

Defendants.

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AUTOMOTIVE TECHNOLOGIES  
INTERNATIONAL, INC.

C.A. No. 06-391-GMS

vs.

HYUNDAI MOTOR AMERICA,  
BMW OF NORTH AMERICA, LLC., and  
KIA MOTORS AMERICA, INC.

Defendants.

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**JOINT STATUS REPORT**

This constitutes the parties' third semiannual status report concerning the above captioned cases, which have been stayed pending the resolution of various *ex-parte* and *inter-parte* requests for reexamination of a number of the patents-in-suit. The requests for reexamination were made by certain of the Defendants in the *ATI v Elesys/Honda* litigation.<sup>1</sup>

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<sup>1</sup> The *Honda* defendants initially sought reexamination of five patents, and subsequently sought reexamination of several additional patents. The eight patents currently in reexamination are the following: U.S. Patent Nos. 6,712,387 ("the '387 patent"), 6,325,414 ("the '414 patent"), 6,942,248 ("the '248 patent"), 6,484,080 ("the '080 patent"), 6,757,602 ("the '602 patent"), 6,422,595 ("the '595 patent"), 6,397,136 ("the '136 patent"), and 5,901,978 ("the '978 patent"). The *Hyundai* defendants have not sought any reexaminations.

### **PLAINTIFF'S POSITION**

The Court may recall that these infringement actions generally concern various systems used in automobiles for sensing the existence, weight, and/or position of an occupant and controlling the deployment of an airbag in response to information sent and/or obtained by the sensing systems. Plaintiff ATI asserted a variety of patents against the party Defendants in these cases, many of which, as noted above, were subject to *ex parte* and *inter parte* re-examination proceedings.

The parties last status report of February, 2008 advised the Court that while the reexamination proceedings have proceeded, the United States Patent and Trademark Office (“PTO”) had confirmed the patentability of at least two ATI patents at issue in the litigation. ATI can now report that the PTO has issued a Reexamination Certificate with respect to U.S. Pat. No. 6, 484, 080 (“the ‘080 Patent”) (*Exhibit A*) and a Final Office Action confirming the patentability of numerous claims of U.S. Pat. No. 6, 757,602 (“the ‘602 Patent”) (*Exhibit B*). Both the ‘080 and the ‘602 Patents have been asserted against Defendants in each of the stayed cases. These will be briefly addressed below as they pertain to the stayed litigation.

#### **‘080 Patent**

ATI asserts numerous claims of the ‘080 Patent against the Defendants. The PTO’s Reexamination Certificate confirms the patentability without amendment of the following twenty-one claims that are at issue<sup>2</sup>: **19**, 20, 22, 24-27, 31, **33**, 35, 36, 38-41, 44, **48**, 53-55, and 59 (independent claims noted in bold). For the Court’s convenience, the independent claims are reproduced below:

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<sup>2</sup> The PTO confirmed the patentability of additional claims that may or may not be at issue in the litigations as well.

**Claim 19**

A method for controlling at least one part of the vehicle comprising the steps of mounting a plurality of sensor systems at different locations on the vehicle;

measuring a state of the sensor system or a state of the respective mounting location of the sensor system;

diagnosing the state of the vehicle based on the measurements of the state of the sensor systems or the state of the mounting locations of the sensor systems, and

controlling the at least one part based at least in part on the diagnosed state of the vehicle.

**Claim 33**

In a motor vehicle, a control system for controlling at least one part of the vehicle comprising:

A plurality of sensor systems mounted on the vehicle, each of said sensor systems providing a measurement of a state of said sensor system and generating a signal representative of the measurement; and

A pattern recognition system for receiving the signals from said sensor systems and diagnosing the state of the vehicle based on the measurements of said sensor systems;

Said pattern recognition system being arranged to generate a control signal for controlling that at least one part based at least in part on the diagnosed state of the vehicle.

**Claim 48**

A method for controlling at least one part of the vehicle, comprising the steps of:

Mounting a plurality of sensor systems on the vehicle;

Measuring a state of the sensor system or a state of the respective mounting location of the sensor system;

Generating signals representative of the measurements of the sensor systems;

Inputting the signals into a pattern recognition system to obtain a diagnosis of the state of the vehicle; and

Controlling the at least one part based at least in part on the diagnosis of the state of the vehicle.

(The '080 Patent is attached as *Exhibit C*). In addition to confirming the patentability of the above claims, the PTO issued twelve new and fifteen amended claims with respect to this patent. Many of these are expected to be asserted in the litigation.

**'602 Patent**

The PTO's Final Office Action confirms the patentability without amendment of the following thirty-one claims at issue in the litigation: **1**, 2, 4, 8-10, **18**, 19, 22-24, 26, 27, 29, 30, **32**, 33, 36-38, 40, 41, 43, 44, **46**, 47, 49, 51, 52, 54, and 55 (independent claims in bold). For the Court's convenience, the independent claims are reproduced below:

**Claim 1**

A method for controlling an occupant protection device in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant in a seat to be protected by the occupant protection device;

classifying the type of occupant based on the acquired data;

when the occupant is classified as an empty seat or a rear-facing child seat, disabling or adjusting deployment of the occupant protection device; otherwise classifying the size of the occupant based on the acquired data;

determining the position of the occupant by means of one of a plurality of algorithms selected based on the classified size of the occupant using the acquired data, each of the algorithms being applicable for a specific size of occupant, and

disabling or adjusting deployment of the occupant protection device when the determined position of the occupant is more likely to result in injury to the occupant if the occupant protection device were to deploy.

**Claim 18**

A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component;

identifying the occupant based on the acquired data; determining the position of the occupant based on the acquired data;

controlling the component based on at least one of the identification of the occupant and the determined position of the occupant;

periodically acquiring new data from the at least one sensor; and

for each time new data is acquired, identifying the occupant based on the acquired new data and an identification from a preceding time and determining the position of the occupant based on the acquired new data and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant.

**Claim 32**

A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component;

identifying an occupant based on the acquired data;

determining the position of the occupant based on the acquired data;

controlling the component based on at least one of the identification of the occupant and the determined position of the occupant;

periodically acquiring new data from the at least one sensor; and

for each time new data is acquired, identifying an occupant based on the acquired new data and determining the position of the occupant based on the acquired new data and a determination of the position of the occupant from a preceding time and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant.

**Claim 46**

A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component;

identifying the occupant based on the acquired data;

when the occupant is identified as a child seat, determining the orientation of the child seat based on the acquired data,

determining the position of the child seat by means of one of a plurality of algorithms selected based on the determined orientation of the child seat, each of the algorithms being applicable for a specific orientation of a child seat, and

controlling the component based on the determined position of the child seat; and

when the occupant is identified as other than a child seat, determining at least one of the size and position of the occupant, and

controlling the component based on the at least one of the size and position of the occupant.

(The '602 Patent is attached as *Exhibit D*). While ATI expects success in the reexamination procedure with respect to several other patents, it believes that there is no further need to wait until the termination of all of the reexamination proceedings before reopening this case. The PTO has now decided that at least fifty-one claims asserted in the litigations are patentable and/or confirmed. These patents and these claims cover infringement by every Defendant. Whether or not the PTO ultimately upholds the patentability of other claims in other patents, there is no reason, from Plaintiff's perspective, to keep these cases stayed. Plaintiff

accordingly asks this Court to schedule a status hearing for the purpose of scheduling the re-commencement of these cases.

### **DEFENDANTS' POSITION**

Defendants maintain that it is entirely premature to consider ATI's suggestion to proceed with part of the case at this time. This case was originally stayed based on the PTO's granting of five reexamination requests. At present, *seven* asserted patents remain in reexamination before the PTO.<sup>3</sup> These patents include asserted claims that stand rejected by the PTO. Defendants believe that it is unlikely that these patents will survive in their original form; however it is simply premature to know what the PTO will do these claim. As evident by the reexamination proceedings for the '080 patent, for example, the presently asserted claims, *i.e.*, claims 1, 6, 9, 10 and 11 were all amended during reexamination.<sup>4</sup>

Moreover, the products accused of infringement and the infringement issues overlap between the allowed patent and those that are still pending in reexamination. Indeed, for all but one defendant, ATI has accused the same products of infringing all of the asserted patents, including those that are still pending in reexamination. Defendants believe that these reexamination proceedings will continue to narrow the issues that remain in these cases. To proceed forward on the few claims that are currently allowed by the PTO, while a majority of the asserted claims of the asserted patents are still pending in reexamination, would only engender piecemeal, duplicative litigation of the worst kind. Thus, Defendants respectfully request that these cases remain stayed pending conclusion of the reexamination proceedings of the asserted patents.

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<sup>3</sup> A reexamination certificate has issued only for the '080 Patent. The patentability of some claims of the '602 Patent is still in question. It is thus premature to declare reexamination of the '602 Patent "complete."

<sup>4</sup> *See, e.g.*, Plaintiff's Preliminary Claim Disclosure dated December 22, 2006, served on Defendant BMWNA.

Dated: August 25, 2008

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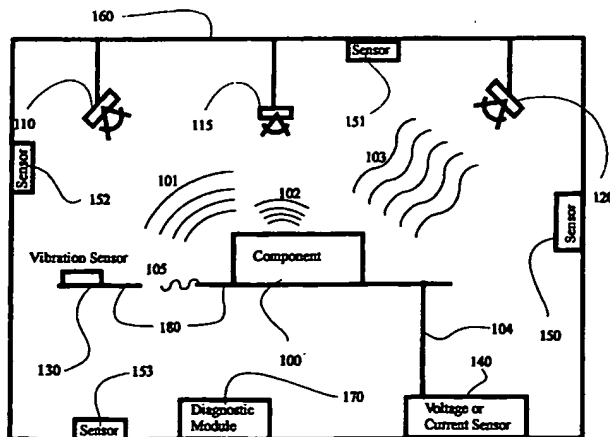
# **EXHIBIT A**



(10) **Number:** US 6,484,080 C1  
(45) **Certificate Issued:** \*Aug. 19, 2008

- |             |         |                      |
|-------------|---------|----------------------|
| 5,161,820 A | 11/1992 | Vollmer              |
| 5,173,614 A | 12/1992 | Woehrl et al.        |
| 5,202,833 A | 4/1993  | Blackburn et al.     |
| 5,219,413 A | 6/1993  | Lineberger           |
| 5,222,761 A | 6/1993  | Kaji et al.          |
| 5,232,243 A | 8/1993  | Blackburn et al.     |
| 5,366,241 A | 11/1994 | Kithil               |
| 5,413,378 A | 5/1995  | Steffens, Jr. et al. |
| 5,446,661 A | 8/1995  | Gioutsos et al.      |
| 5,454,591 A | 10/1995 | Mazur et al.         |
| 5,481,906 A | 1/1996  | Nagayoshi et al.     |
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| 5,585,775 A | 12/1996 | Ishishita            |
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| 5,612,876 A | 3/1997  | Zeidler et al.       |

Control system and method for controlling a part of the vehicle in which sensor systems are mounted at different locations on the vehicle, each sensor system providing a measurement related to a state of the sensor system or a measurement related to a state of the mounting location. A processor coupled to the sensor systems diagnoses the state of the vehicle based on the measurements of the sensor system, e.g., by the application of a pattern recognition technique. The processor controls the part based at least in part on the diagnosed state of the vehicle. At least one of the sensor systems may be a high dynamic range accelerometer or a sensor selected from a group consisting of a single axis acceleration sensor, a double axis acceleration sensor, a tri-axis acceleration sensor and a gyroscope, and may optionally include an RFID response unit.



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## U.S. PATENT DOCUMENTS

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 5,683,103 A 11/1997 Blackburn et al.  
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 5,948,031 A 9/1999 Jinno et al.  
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 6,015,163 A 1/2000 Langford et al.  
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 6,088,640 A 7/2000 Breed  
 6,397,677 B1 6/2002 Kinsley et al.

## OTHER PUBLICATIONS

Abstract of German Patent Publication No. DE 3809074.  
 Abstract of German Patent Publication No. DE 3836712.  
 Abstract of German Patent Publication No. DE 4023109.  
 Abstract of German Patent Publication No. DE 4115202.  
 Abstract of German Patent Publication No. DE 4133237.  
 Abstract of German Patent Publication No. DE 4237072.  
 Abstract of German Patent Publication No. DE 19530092.  
 Abstract of German Patent Publication No. DE 19706623.  
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 Description of German Patent Publication No. DE 8706578.  
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A Critique of Single Point Crash Sensing, David S. Breed et al., SAE Paper No. 920124.

Trends in Sensing Frontal Impacts, David S. Breed et al., SAE Paper No. 890750.

Vehicle Occupant Position Sensing, David S. Breed et al., SAE Paper No. 940527.

Mechanical Versus Accelerometer Based Sensing for Supplemental Inflatable Restraint Systems, Tony D. Hendrix et al, AES Paper No. 901121, pp. 13-22.

Electronic Crash Sensors for Restraint Systems, Dietrich E. Bergfried et al., Paper No. 901136, pp. 169-177.

Airbag Systems—Their Permanent Monitoring and Its Meaning to the User, Alfons Hartl et al., Siemens Automotive, Paper No. 901138, pp. 187-193.

Using Seat Mounted Accelerometers to Differentiate Between Normally Seated Passengers and Infants in Infant Seats, Alan L. Browne et al., GM R&D, Paper No. 933092, pp. 147-162.

The Use of Signal Processing Techniques in an Occupant Detection System, Edward J. Gillis et al., Automotive Systems, Paper No. 940906, pp. 65-70.

The BMW Seat Occupancy Monitoring System: A Step Towards Situation Appropriate Airbag Deployment, Klaus Kompass et al., SAE Paper No. 960226, pp. 17-25.

The New Generation of the BMW Child Seat and Occupant Detection System SBE 2, Yan Lu et al., Int'l Journal of Automotive Technology, vol. 3, No. 2, pp. 53-56.

Injury Reduction Potential for "Smart" Airbags, Steven R. Fredin, 39<sup>th</sup> Annual Proceedings Association for the Advancement of Automotive Medicine, Oct. 16-18, 1995, pp. 557-565.

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## EX PARTE

REEXAMINATION CERTIFICATE  
ISSUED UNDER 35 U.S.C. 307THE PATENT IS HEREBY AMENDED AS  
INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims 19, 20, 22, 24-29, 31, 33-35, 39-42, 44, 47-49, 53-56 and 59 is confirmed.

Claims 1, 4, 7, 10-15, 18, 36-38, 46, 52, and 60 are determined to be patentable as amended.

Claims 2, 6, 8, 9, 61 and 62, dependent on an amended claim, are determined to be patentable.

New claims 63-75 are added and determined to be patentable.

Claims 3, 5, 16, 17, 21, 23, 30, 32, 43, 45, 50, 51, 57 and 58 were not reexamined.

1. In a motor vehicle, a control system for controlling at least one part of the vehicle comprising:

a plurality of *different* sensor systems mounted at different locations on the vehicle, each of said sensor systems providing a measurement related to a state of said sensor system or a measurement related to a state of the mounting location; and

a processor coupled to said sensor systems and arranged to diagnose the [state] *overall condition* of the vehicle based on the measurements of said sensor systems, *the diagnosis of the overall condition of the vehicle being a diagnosis of the condition of the vehicle with respect to its stability,*

said processor being arranged to control the at least one part based at least in part on the diagnosed [state] *overall condition* of the vehicle.

4. The vehicle of claim 1, wherein the [state] *overall condition* of the vehicle diagnosed by said processor includes angular motion of the vehicle.

7. The vehicle of claim 1, wherein the [state] *overall condition* of the vehicle diagnosed by said processor includes a determination of a location of an impact between the vehicle and another object.

10. The vehicle of claim 9, further comprising a weight sensing system coupled to a seat in the vehicle for sensing the weight of an occupying item of the seat, said weight sensing system being coupled to said processor and said processor controlling the occupant restraint device based on the [state] *overall condition* of the vehicle and the weight of the occupying item of the seat sensed by said weight sensing system.

11. The vehicle of claim 1, wherein said processor includes pattern recognition means for diagnosing the [state] *overall condition* of the vehicle.

12. The vehicle of claim 1, further comprising a display coupled to said processor for displaying an indication of the [state] *overall condition* of the vehicle as diagnosed by said processor.

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13. The vehicle of claim 1, further comprising a warning device coupled to said processor for relaying a warning to an occupant of the vehicle relating to the [state] *overall condition* of the vehicle as diagnosed by said processor.

14. The vehicle of claim 1, further comprising a transmission device coupled to said processor for transmitting a signal to a remote site relating to the [state] *overall condition* of the vehicle as diagnosed by said processor.

15. The vehicle of claim 1, wherein the [state] *overall condition* of the vehicle includes angular acceleration, a plurality of said sensor systems comprising accelerometers such that said processor determines the angular acceleration of the vehicle based on the acceleration measured by said accelerometers.

18. The vehicle of claim 1, wherein the [state] *overall condition* of the vehicle diagnosed by said processor includes angular acceleration of the vehicle whereby angular velocity and angular position or orientation are derivable from the angular acceleration the at least one part being a navigation system, said processor being arranged to control said navigation system based on the angular acceleration of the vehicle.

36. The vehicle of claim 33, wherein the state of the vehicle diagnosed by said [processor] *pattern recognition system* includes angular orientation, velocity or acceleration of the vehicle.

37. The vehicle of claim 33, wherein the at least one part is a system selected from a group consisting of a steering system, a braking system or a throttle system, said [processor] *pattern recognition system* being arranged to control the system in an attempt to maintain stability of the vehicle.

38. The vehicle of claim 33, wherein the at least one part is an occupant restraint device, said [processor] *pattern recognition system* being arranged to control the occupant restraint device in an attempt to minimize injury to an occupant.

46. The [method] *vehicle* of claim 33, wherein said pattern recognition system comprises a neural network system and the state of the vehicle diagnosed by said neural network system includes a state of an abnormally operating component, said neural network system including a first neural network arranged to identify a potentially malfunctioning component based on the state of the component measured by said sensor systems and a plurality of additional neural networks, each being trained to determine whether a specific component is operating abnormally, whereby the measurements of the state of the component from said sensor systems are input into that one of the additional neural networks trained on a component which is substantially identical to the identified component.

52. The method of claim 48, wherein the at least one part is an occupant restraint device, the step of controlling the at least one part comprising the [steps] *step* of controlling the system in an attempt to minimize injury to an occupant in the event of a crash.

60. In a motor vehicle having a seat, a control system for controlling at least one part of the vehicle based on occupancy of the seat, comprising:

a plurality of sensor systems mounted at different locations on the vehicle, each of said sensor systems providing a measurement related to a state of said sensor system or a measurement related to a state of the mounting location,

a plurality of strain gages mounted in connection with the seat, each of said strain gages measuring strain of a respective mounting location caused by occupancy of the seat, and

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a processor coupled to said strain gages and to said sensor systems and arranged to determine the weight of an occupying item based on the strain measurements from said strain gages over a period of time and diagnose the state of the vehicle based on the measurements of said sensor systems,

said processor being arranged to control the at least one part based at least in part on the determined weight of the occupying item of the seat and the diagnosed state of the vehicle.

63. The vehicle of claim 60, wherein said sensor systems are different sensor systems and the diagnosis of the state of the vehicle is other than a diagnosis of the state of the at least one part.

64. The vehicle of claim 60, wherein the at least one part is an occupant restraint or protection device which restrains or protects an occupant in a crash involving the vehicle, said processor being arranged to control said occupant restraint or protection device.

65. The vehicle of claim 64, wherein the diagnosis of the state of the vehicle is a diagnosis of the condition of the vehicle with respect to whether the vehicle is experiencing excessive angular inclination, the vehicle is experiencing a crash or the vehicle is skidding.

66. The vehicle of claim 1, wherein said sensor systems are mounted separate and apart from the at least one part being controlled by said processor.

67. The method of claim 19, wherein the diagnosis of the state of the vehicle is a diagnosis of the condition of the vehicle with respect to its stability.

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68. The method of claim 19, wherein the sensor systems are different sensor systems and the diagnosis of the state of the vehicle is other than a diagnosis of the state of the at least one part.

69. The method of claim 19, wherein the step of mounting the sensor systems at different locations on the vehicle comprises mounting the sensor systems separate and apart from the at least one part being controlled.

70. The vehicle of claim 33, wherein the diagnosis of the state of the vehicle is a diagnosis of the condition of the vehicle with respect to its stability.

71. The vehicle of claim 33, wherein the diagnosis of the state of the vehicle is other than a diagnosis of the state of the at least one part.

72. The vehicle of claim 33, wherein said sensor systems are mounted separate and apart from the at least one part being controlled by said processor.

73. The method of claim 48, wherein the state of the vehicle is a diagnosis of the condition of the vehicle with respect to its stability.

74. The method of claim 48, wherein the diagnosis of the state of the vehicle is other than a diagnosis of the state of the at least one part.

75. The method of claim 48, wherein the step of mounting the sensor systems on the vehicle comprises mounting the sensor systems separate and apart from the at least one part being controlled.

\* \* \* \* \*

# **EXHIBIT B**



## UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE  
United States Patent and Trademark Office  
Address: COMMISSIONER FOR PATENTS  
P.O. Box 1450  
Alexandria, Virginia 22313-1450  
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
90/008,350	11/27/2006	6,757,602 B2	ATI-314 RE	4684
22846	7590	01/18/2008	EXAMINER	
BRIAN ROFFE, ESQ 11 SUNRISE PLAZA, SUITE 303 VALLEY STREAM, NY 11580-6111			ART UNIT	PAPER NUMBER

DATE MAILED: 01/18/2008

Please find below and/or attached an Office communication concerning this application or proceeding.



UNITED STATES PATENT AND TRADEMARK OFFICE

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United States Patent and Trademark Office  
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**EX PARTE REEXAMINATION COMMUNICATION TRANSMITTAL FORM**

REEXAMINATION CONTROL NO. 90/008,350.

PATENT NO. 6,757,602 B2 ET.

ART UNIT 3993.

Enclosed is a copy of the latest communication from the United States Patent and Trademark Office in the above identified *ex parte* reexamination proceeding (37 CFR 1.550(f)).

Where this copy is supplied after the reply by requester, 37 CFR 1.535, or the time for filing a reply has passed, no submission on behalf of the *ex parte* reexamination requester will be acknowledged or considered (37 CFR 1.550(g)).

<b>Office Action in Ex Parte Reexamination</b>	<b>Control No.</b> 90/008,350	<b>Patent Under Reexamination</b> 6,757,602 B2 ET	
	<b>Examiner</b> Peter C. English	<b>Art Unit</b> 3993	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

- a ☒ Responsive to the communication(s) filed on 19 November 2007.      b ☒ This action is made FINAL.  
c ☐ A statement under 37 CFR 1.530 has not been received from the patent owner.

A shortened statutory period for response to this action is set to expire 1 month(s) from the mailing date of this letter. Failure to respond within the period for response will result in termination of the proceeding and issuance of an *ex parte* reexamination certificate in accordance with this action. 37 CFR 1.550(d). **EXTENSIONS OF TIME ARE GOVERNED BY 37 CFR 1.550(c).** If the period for response specified above is less than thirty (30) days, a response within the statutory minimum of thirty (30) days will be considered timely.

Part I THE FOLLOWING ATTACHMENT(S) ARE PART OF THIS ACTION:

1. ☐ Notice of References Cited by Examiner, PTO-892.      3. ☐ Interview Summary, PTO-474.  
2. ☒ Information Disclosure Statement, PTO/SB/08.      4. ☐ \_\_\_\_\_.

Part II SUMMARY OF ACTION

- 1a. ☒ Claims 1,2,4,8-10,12-15,18,19,22-27,29,30,32,33,36-41,43,44,46,47,49,51,52,54 and 55 are subject to reexamination.  
1b. ☒ Claims 3,5-7,11,28,31,42,45,48,50,53 and 56 are not subject to reexamination.  
2. ☒ Claims 16,17,20,21,34 and 35 have been canceled in the present reexamination proceeding.  
3. ☒ Claims 1,2,4,8-10,18,19,22-24,26,27,29,30,32,33,36-38,40,41,43,44,46,47,49,51,52,54 and 55 are patentable and/or confirmed.

4. ☒ Claims 12-15,25 and 39 are rejected.  
5. ☐ Claims \_\_\_\_\_ are objected to.  
6. ☐ The drawings, filed on \_\_\_\_\_ are acceptable.  
7. ☐ The proposed drawing correction, filed on \_\_\_\_\_ has been (7a) ☐ approved (7b) ☐ disapproved.  
8. ☐ Acknowledgment is made of the priority claim under 35 U.S.C. § 119(a)-(d) or (f).

a) ☐ All b) ☐ Some\* c) ☐ None of the certified copies have

1 ☐ been received.

2 ☐ not been received.

3 ☐ been filed in Application No. \_\_\_\_\_.

4 ☐ been filed in reexamination Control No. \_\_\_\_\_.

5 ☐ been received by the International Bureau in PCT application No. \_\_\_\_\_.

\* See the attached detailed Office action for a list of the certified copies not received.

9. ☐ Since the proceeding appears to be in condition for issuance of an *ex parte* reexamination certificate except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte* Quayle, 1935 C.D. 11, 453 O.G. 213.  
10. ☐ Other: \_\_\_\_\_

cc: Requester (if third party requester)



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## **DETAILED ACTION**

### ***Finality Withdrawn***

1. The finality of the Office action mailed on 19 October 2007 is withdrawn because the action improperly indicated that amended claims 12-15, 25 and 39 would not be reexamined. Even though reexamination of original claims 17 (rewritten in independent form as amended claim 12), 25 and 39 was not requested, claims 12, 25 and 39 are now subject to reexamination because patent owner has amended these claims.

### ***Entry of Amendment***

2. The amendment filed on 19 November 2007 has been approved for entry by the examiner.

### ***Claim Rejections - 35 USC § 103***

3. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

4. Claims 12-15, 25 and 39 are rejected under 35 U.S.C. 103(a) as being unpatentable over Corrado et al. (US 5,482,314) in view of Breed et al. (GB 2,289,332). NOTE: Corrado et al. was cited in Patent Number 6,757,602, but Breed et al. was not cited in the patent.

Corrado et al. discloses a method for controlling an airbag system in a vehicle, comprising: acquiring data relating to seat occupancy from infrared sensors and ultrasonic sensors 24, 26 (see column 12, lines 28-30 and 58-63; column 14, lines 1-10); using the acquired data to classify the seat occupancy, i.e., distinguishing between an empty seat, an inanimate object in the seat, an out-of-position occupant, a properly positioned occupant, and a rear-facing child seat (see column 10, line 43 to column 11, line 5; column 11, lines 34-52); inhibiting

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deployment of the airbag when the seat occupancy is classified as an empty seat, an inanimate object in the seat, an out-of-position occupant, and a rear-facing child seat (see column 11, lines 34-52; column 12, lines 1-14); and enabling deployment of the airbag when the seat occupancy is classified as a properly positioned occupant (see column 11, lines 34-58). Classifying the seat occupancy includes both identifying the type of occupant/object in the seat and determining the position of the occupant/object in the seat (see column 10, line 43 to column 11, line 5; column 11, lines 53-67; column 18, lines 2-12; column 19, lines 5-9). Classifying the seat occupancy is based on newly acquired sensor data as well as previously acquired sensor data (see column 15, lines 18-39; column 19, line 24 to column 20, line 26). Pattern recognition algorithms are used to classify the seat occupancy (see column 14, lines 22-27; column 15, line 18 to column 16, line 41). Instead of inhibiting deployment of the airbag, the airbag pressure can be reduced when the seat occupancy is classified as an empty seat, an inanimate object in the seat, an out-of-position occupant, and a rear-facing child seat (see column 12, lines 15-26).

Corrado et al. fails to teach the use of a neural network. Breed et al. teaches the use of a pattern recognition system, and particularly the use of a neural network, in distinguishing between seated vehicle occupants and objects (see the abstract). The neural network provides more sophisticated pattern recognition capabilities (see page 6, lines 12-15) and is capable of identifying, classifying and locating a seated occupant/object while providing the greatest possible information about the occupant/object at a rapid data rate (see page 8, lines 23-27). The sophistication of the neural network is due to its ability to be trained to recognize slight differences between complicated patterns of sensor data in order to accurately differentiate between different types of seated occupants/objects (see page 20, line 6 to page 21, line 27). From this teaching of Breed et al., it would have been obvious to one of ordinary skill in the art at the time the invention was made to modify Corrado et al. by using a neural network to classify the seat occupancy because a neural network provides more sophisticated pattern recognition capabilities due to its ability to be trained to recognize slight differences between complicated patterns of sensor data in order to accurately differentiate between different types of seated occupants/objects.

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***Patentable Claims***

5. The following is an examiner's statement of reasons for patentability and/or confirmation of the claims found patentable in this reexamination proceeding:

Claim 1 is confirmed as patentable because the cited prior art patents and printed publications fail to teach a method for controlling a vehicle component, as defined in this claim, including determining the position of an occupant by means of one of a plurality of algorithms, the plurality of algorithms each applicable to a specific occupant size, with the position of an occupant determined by selecting one of the algorithms based on the classified size of an occupant.

Claims 2, 4 and 8-10 are confirmed as patentable because of their dependency from claim 1.

Claims 18 and 32 are patentable because the cited prior art patents and printed publications fail to teach a method for controlling a vehicle component, as defined in these claims, wherein the step of identifying the occupant based on the acquired data comprises using data from a first group of the plurality of sensors and the step of determining the position of the occupant based on the acquired data comprises using data from a second group of the plurality of sensors different than the first group.

Claims 19 and 22-24 are patentable because of their dependency from claim 18; and claims 33 and 36-38 are patentable because of their dependency from claim 32.

Claims 26 and 40 are patentable because the cited prior art patents and printed publications fail to teach a method for controlling a vehicle component, as defined in these claims, wherein the step of determining the position of an occupant comprises inputting data into one of a plurality of algorithms, the plurality of algorithms each applicable to a specific occupant identification, with the position of an occupant determined by selecting one of the algorithms based on the identification of the occupant and inputting the acquired data into the selected algorithm.

Claims 27 and 41 are patentable because of their dependency from claims 26 and 40, respectively.

Claims 29 and 43 are patentable because the cited prior art patents and printed publications fail to teach a method for controlling a vehicle component, as defined in these

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claims, wherein the step of determining the position of an occupant comprises inputting data into one of a plurality of algorithms, the plurality of algorithms each applicable to a specific occupant size, with the position of an occupant determined by selecting one of the algorithms based on the classified size of the occupant and inputting the acquired data into the selected algorithm.

Claims 30 and 44 are patentable because of their dependency from claims 29 and 43, respectively.

Claim 46 is confirmed as patentable because the cited prior art patents and printed publications fail to teach a method for controlling a vehicle component, as defined in this claim, including determining the position of a child seat by means of one of a plurality of algorithms, the plurality of algorithms each applicable to a specific child seat orientation, with the position of a child seat determined by selecting one of the algorithms based on the determined orientation of the child seat.

Claims 47, 49, 51, 52, 54 and 55 are confirmed as patentable because of their dependency from claim 46.

#### ***Not All Claims Reexamined***

6. This action is directed only to (1) claims for which reexamination was requested, and (2) claims which have been amended by patent owner. With respect to claims for which reexamination was requested, requester has alleged that a substantial new question of patentability (SNQ) exists, and upon review, it has been determined that the alleged SNQ in fact is present for claims 1, 2, 4, 8-10, 12-15, 18, 19, 22-24, 26, 27, 29, 30, 32, 33, 36-38, 40, 41, 43, 44, 46, 47, 49, 51, 52, 54 and 55. In addition to the claims for which reexamination was requested, patent owner has amended claims 25 and 39; therefore, these claims are also subject to reexamination.

No determination was made with respect to the existence or nonexistence of a SNQ with respect to claims 3, 5-7, 11, 28, 31, 42, 45, 48, 50, 53 and 56 for which reexamination was not specifically requested, and these claims have not been amended by patent owner. Therefore, these claims are not subject to reexamination.

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***Final Action***

7. Patent owner's amendments filed on 30 May 2007 and 19 November 2007 necessitated the new grounds of rejection presented in this Office action. Accordingly, **THIS ACTION IS MADE FINAL**. See MPEP § 706.07(a).

8. Litigation involving Patent No. 6,757,602 (*Automotive Technologies v. American Honda, US District-Delaware, 1:06cv187*; and *Automotive Technologies v. Hyundai Motor America, US District-Delaware, 1:06cv391*) has been stayed for the purposes of reexamination. Accordingly, a shortened statutory period of 1 month is set for response to Office actions in this proceeding. See MPEP 2263.

9. Extensions of time under 37 CFR 1.136(a) do not apply in reexamination proceedings. The provisions of 37 CFR 1.136 apply only to "an applicant" and not to parties in a reexamination proceeding. Further, in 35 U.S.C. 305 and in 37 CFR 1.550(a), it is required that reexamination proceedings "will be conducted with special dispatch within the Office."

Extensions of time in reexamination proceedings are provided for in 37 CFR 1.550(c). A request for extension of time must be filed on or before the day on which a response to this action is due, and it must be accompanied by the petition fee set forth in 37 CFR 1.17(g). The mere filing of a request will not effect any extension of time. An extension of time will be granted only for sufficient cause, and for a reasonable time specified.

The filing of a timely first response to this final rejection will be construed as including a request to extend the shortened statutory period for an additional month, which will be granted even if previous extensions have been granted. In no event, however, will the statutory period for response expire later than SIX MONTHS from the mailing date of the final action. See MPEP § 2265.

***Remarks***

10. Any proposed amendment filed in this reexamination proceeding must be made in accordance with 37 CFR 1.530(d)-(j) and comply with the formal requirements of 37 CFR 1.52(a) and (b). See MPEP 2250.

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11. Responses to this Office action may be submitted by facsimile and should be directed to the Central Reexamination Unit using facsimile number 571-273-9900. A confirmation of receipt will be generated automatically for all papers transmitted via this facsimile number.

All responses to be delivered by the United States Postal Service (USPS) should be addressed as follows:

Mail Stop Ex Parte Reexam  
Central Reexamination Unit  
Commissioner for Patents  
PO Box 1450  
Alexandria, VA 22313-1450

Hand-delivered responses should be labeled "Attn: Central Reexamination Unit" and delivered to:

Customer Service Window  
Randolph Building, Lobby Level  
401 Dulany Street  
Alexandria, VA 22314

Submissions for reexamination proceedings may also be submitted through EFS-Web (the USPTO's web-based document submission system).

12. Any document filed by either the patent owner or third party requester ***must be served*** on the other party (or parties in a merged proceeding) in the reexamination proceeding in the manner provided by 37 CFR 1.248. See 37 CFR 1.550(f) and MPEP 2266.03.

13. 37 CFR 1.33(c) has been revised to provide that the patent owner's correspondence address for all communications in an *ex parte* reexamination or an *inter partes* reexamination is designated as the correspondence address of the patent. See *Revisions and Technical Corrections Affecting Requirements for Ex Parte and Inter Partes Reexamination*, 72 FR 18892 (April 16, 2007)(Final Rule).

The correspondence address for any pending reexamination proceeding not having the same correspondence address as that of the patent is, by way of this revision to 37 CFR 1.33(c), automatically changed to that of the patent file as of the effective date. This change is effective

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for any reexamination proceeding which is pending before the Office as of May 16, 2007, including the present reexamination proceeding, and to any reexamination proceeding which is filed after that date. ***Parties are to take this change into account when filing papers***, and direct communications accordingly.

In the event the patent owner's correspondence address listed in the papers (record) for the present proceeding is different from the correspondence address of the patent, it is strongly encouraged that the patent owner affirmatively file a Notification of Change of Correspondence Address in the reexamination proceeding and/or the patent (depending on which address patent owner desires), to conform the address of the proceeding with that of the patent and to clarify the record as to which address should be used for correspondence.

14. The patent owner is reminded of the continuing responsibility under 37 CFR 1.565(a) to apprise the Office of any litigation activity, or other prior or concurrent proceeding, involving the patent throughout the course of this reexamination proceeding. The third party requester is also reminded of the ability to similarly apprise the Office of any such activity or proceeding throughout the course of this reexamination proceeding. See MPEP §§ 2207, 2282 and 2286.

15. Any inquiry concerning this communication or earlier communications from the Reexamination Examiner should be directed to Peter English whose telephone number is 571-272-6671. The examiner can normally be reached on Monday through Thursday (7:00 AM - 5:00 PM). If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Andres Kashnikow, can be reached at 571-272-4361.

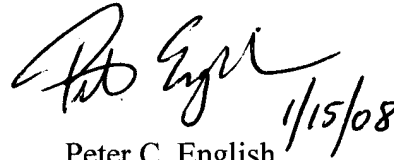
For general information regarding reexamination proceedings please call the Central Reexamination Unit at 571-272-7705. For guidance on reexamination practice and procedure please call the Office of Patent Legal Administration at 571-272-7703. Information regarding this reexamination proceeding may be obtained from the Patent Application Information

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Retrieval (PAIR) system. For more information about the PAIR system, see <http://pair-direct.uspto.gov>.

A handwritten signature in black ink, appearing to read "Peter C. English", with the date "1/15/08" written below it.

Peter C. English  
Primary Examiner  
Central Reexamination Unit

Conferees:   


pe  
15 January 2008



# **EXHIBIT C**

(10) **Patent No.:** US 6,484,080 B2  
(45) **Date of Patent:** \*Nov. 19, 2002

5,123,017	A	6/1992	Simpkins et al. ....	714/26
5,164,901	A	11/1992	Blackburn et al. ....	701/47
5,313,407	A	5/1994	Tiernan et al. ....	364/508
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5,400,018	A	3/1995	Scholl et al. ....	340/825.54
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5,420,794	A	5/1995	James ....	701/117
5,442,553	A	8/1995	Parrillo ....	364/424.04
5,481,906	A	1/1996	Nagayoshi et al. ....	73/116
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(List continued on next page.)

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WO 00/29257 5/2000

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Liubakka et al., "Failure Detection Algorithm Applied To Control System Design For Improved Diagnostic And Reliability", SAE Technical Paper Series, 02-29 To 04-04, 1988, pp. 1-7.

(List continued on next page.)

*Primary Examiner*—Yonel Beaulieu

(74) *Attorney, Agent, or Firm*—Brian Roffe

(57) **ABSTRACT**

(63) Continuation-in-part of application No. 09/137,918, filed on Aug. 20, 1998, now Pat. No. 6,175,787, which is a continuation-in-part of application No. 08/476,077, filed on Jun. 7, 1995, now Pat. No. 5,809,437

(60) Provisional application No. 60/231,378, filed on Sep. 8, 2000.

(51) **Int. Cl.**<sup>7</sup> ..... **G06F 7/00**

(52) **U.S. Cl.** ..... **701/36; 701/29; 701/34**

(58) **Field of Search** ..... 701/29, 30, 34, 701/36, 45; 340/438, 439; 307/9.1

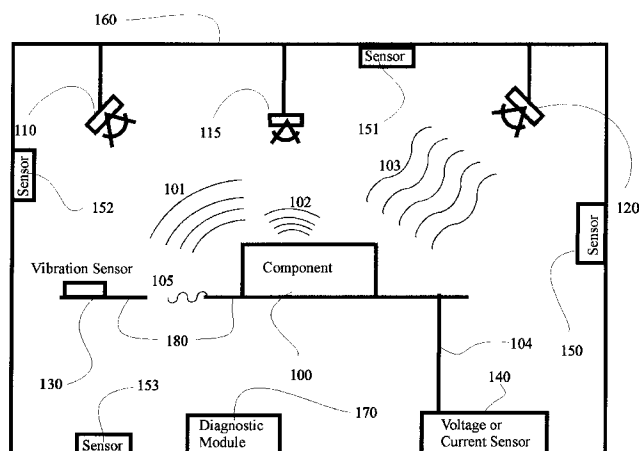
(56) **References Cited**

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4,418,388	A	11/1983	Allgor et al. ....	364/431.01
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4,989,146	A	1/1991	Imajo .....	701/29
5,041,976	A	8/1991	Marko et al. ....	364/424.03

Control system and method for controlling a part of the vehicle in which sensor systems are mounted at different locations on the vehicle, each sensor system providing a measurement related to a state of the sensor system or a measurement related to a state of the mounting location. A processor coupled to the sensor systems diagnoses the state of the vehicle based on the measurements of the sensor system, e.g., by the application of a pattern recognition technique. The processor controls the part based at least in part on the diagnosed state of the vehicle. At least one of the sensor systems may be a high dynamic range accelerometer or a sensor selected from a group consisting of a single axis acceleration sensor, a double axis acceleration sensor, a triaxial acceleration sensor and a gyroscope, and may optionally include an RFID response unit.

**62 Claims, 7 Drawing Sheets**



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V.K. Varadan et al., “Conformal MEMS–IDT Gyroscopes and Their Comparison with Fiber Optic Gyro, Smart Structures and Materials 2000”, Smart Electronics and MEMS, Proceedings of SPIE vol. 3990 (2000), pp. 335–344.

H.K. Tonshoff et al., “Using Acoustic Emission Signals for Monitoring of Production Processes”, Ultrasonics 37 (2000), pp. 681–686, 2000.

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Microsensors, Microelectronmechanical Systems (MEMS), and Electronics for Smart Structures and Systems, V.K. Varadan et al., Smart Mater. Struct., vol. 9, Feb., 1999, pp. 953–972.

Abstract of Wireless Remote Accelerometer, V.K. Varadan et al., in Physics of Semiconductor Devices, vol. 1: Proceedings of the 9<sup>th</sup> International Workshop on Physics of Semiconductor Devices (IWPSD), Delhi, India, Dec. 6–20, 1997.

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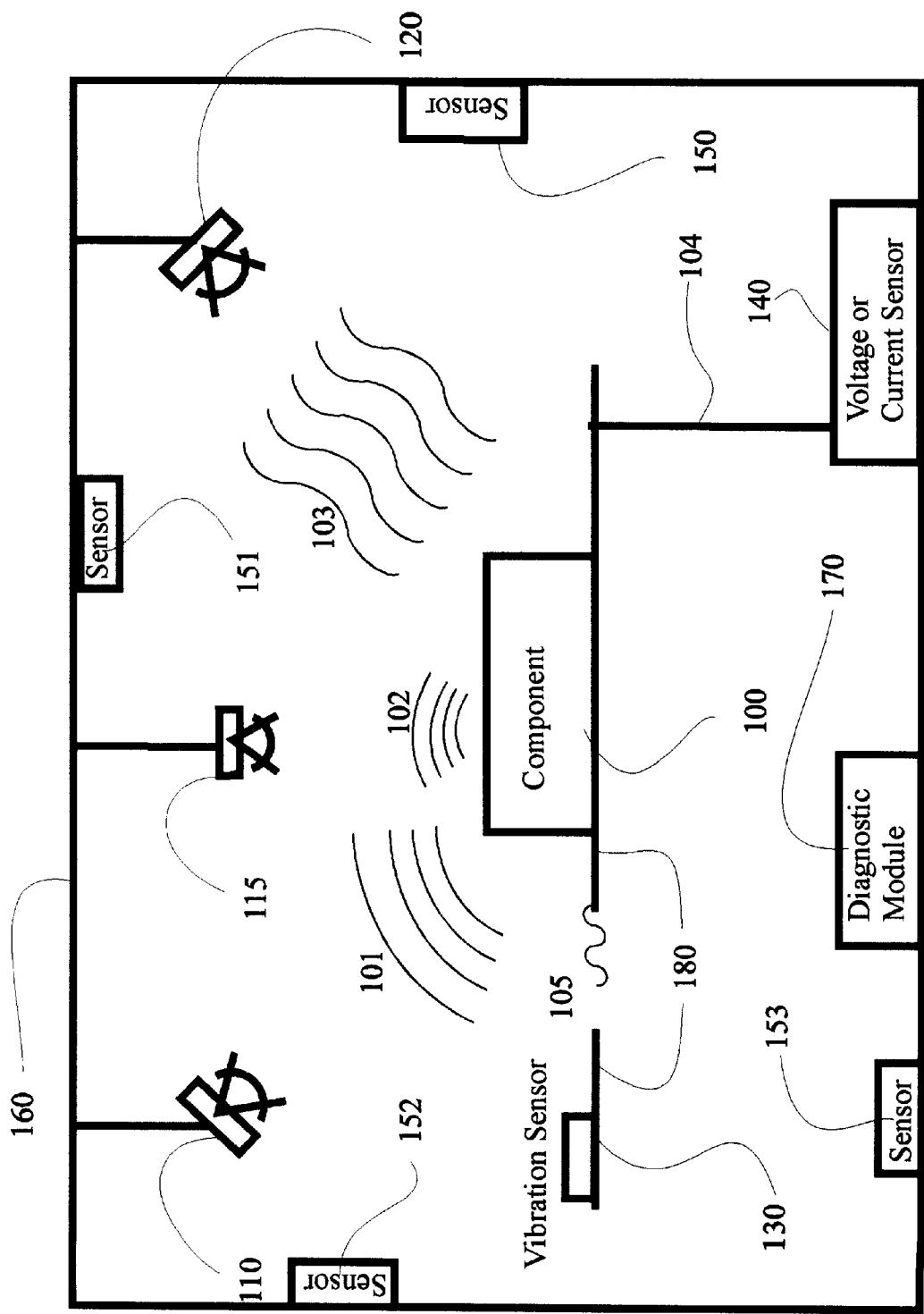


Fig. 1

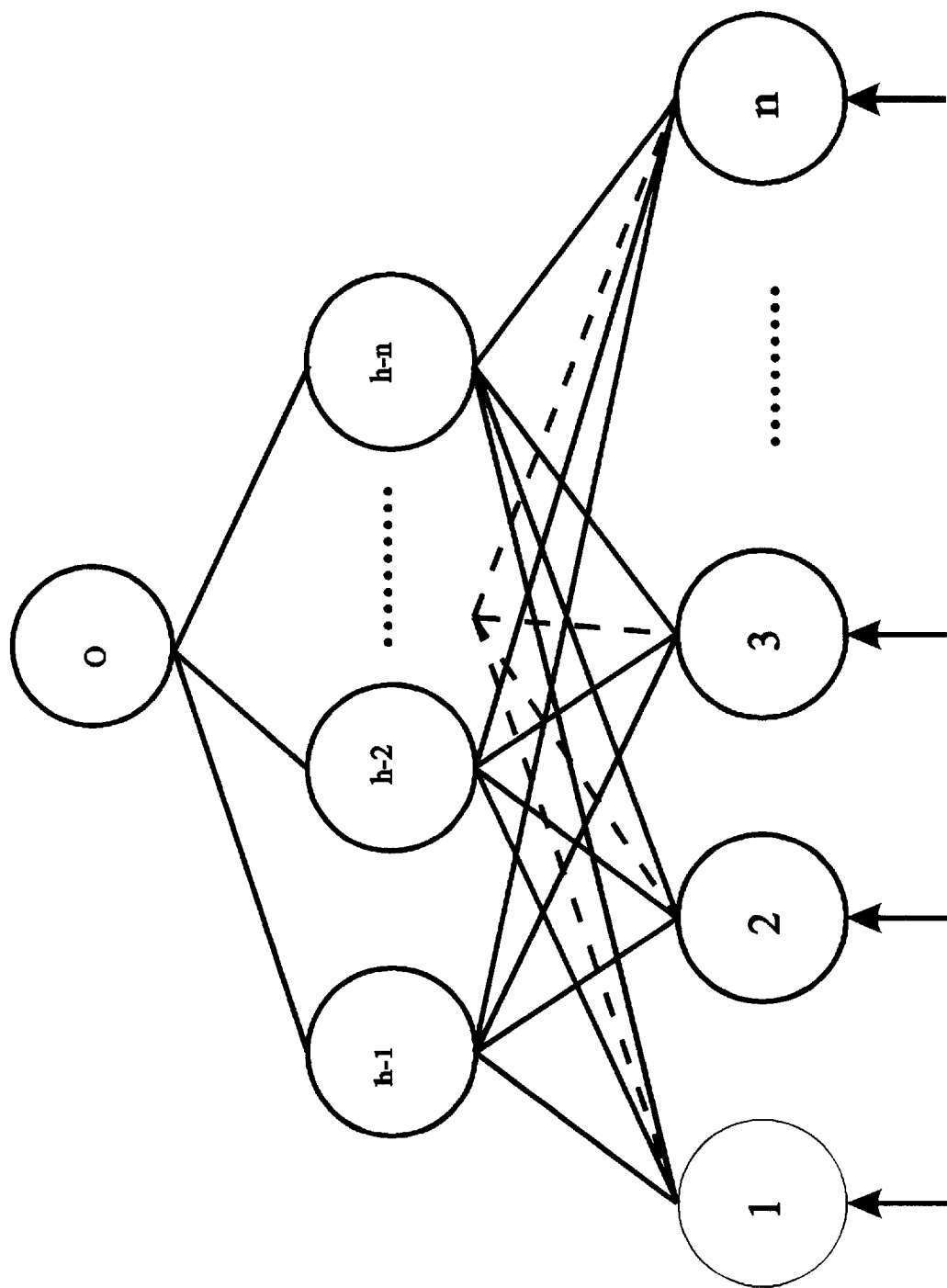


Fig. 2

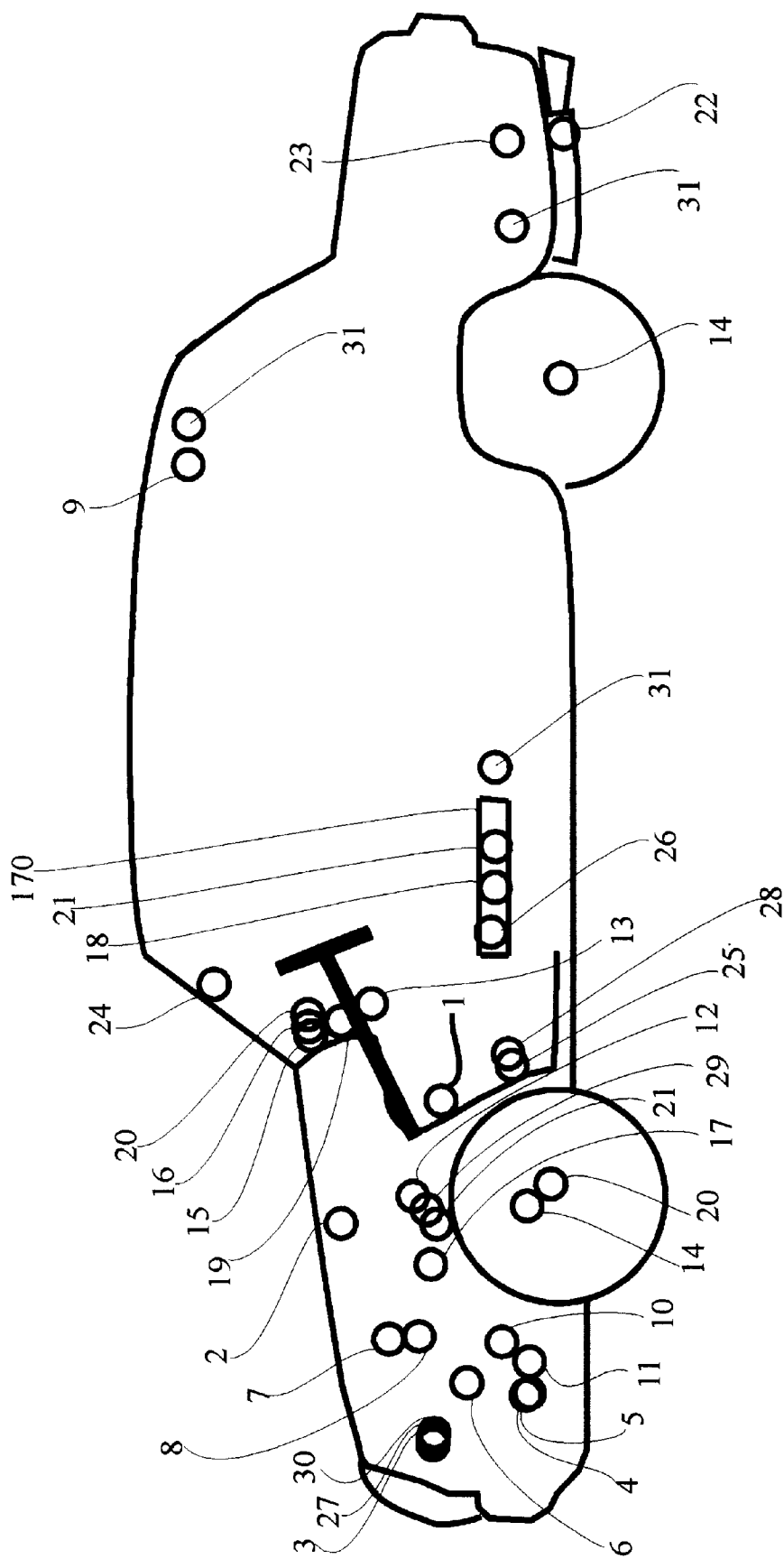


Fig. 3

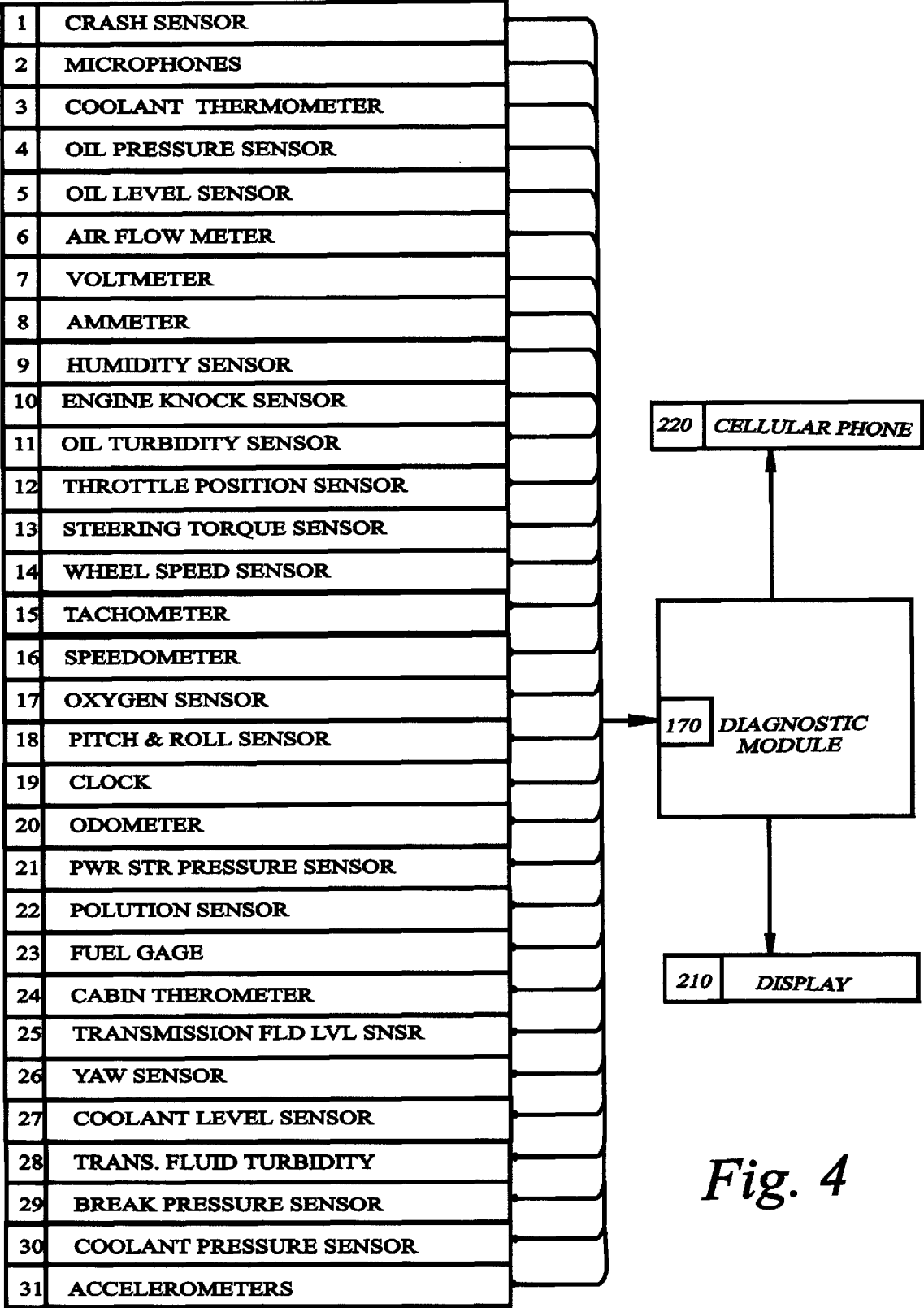
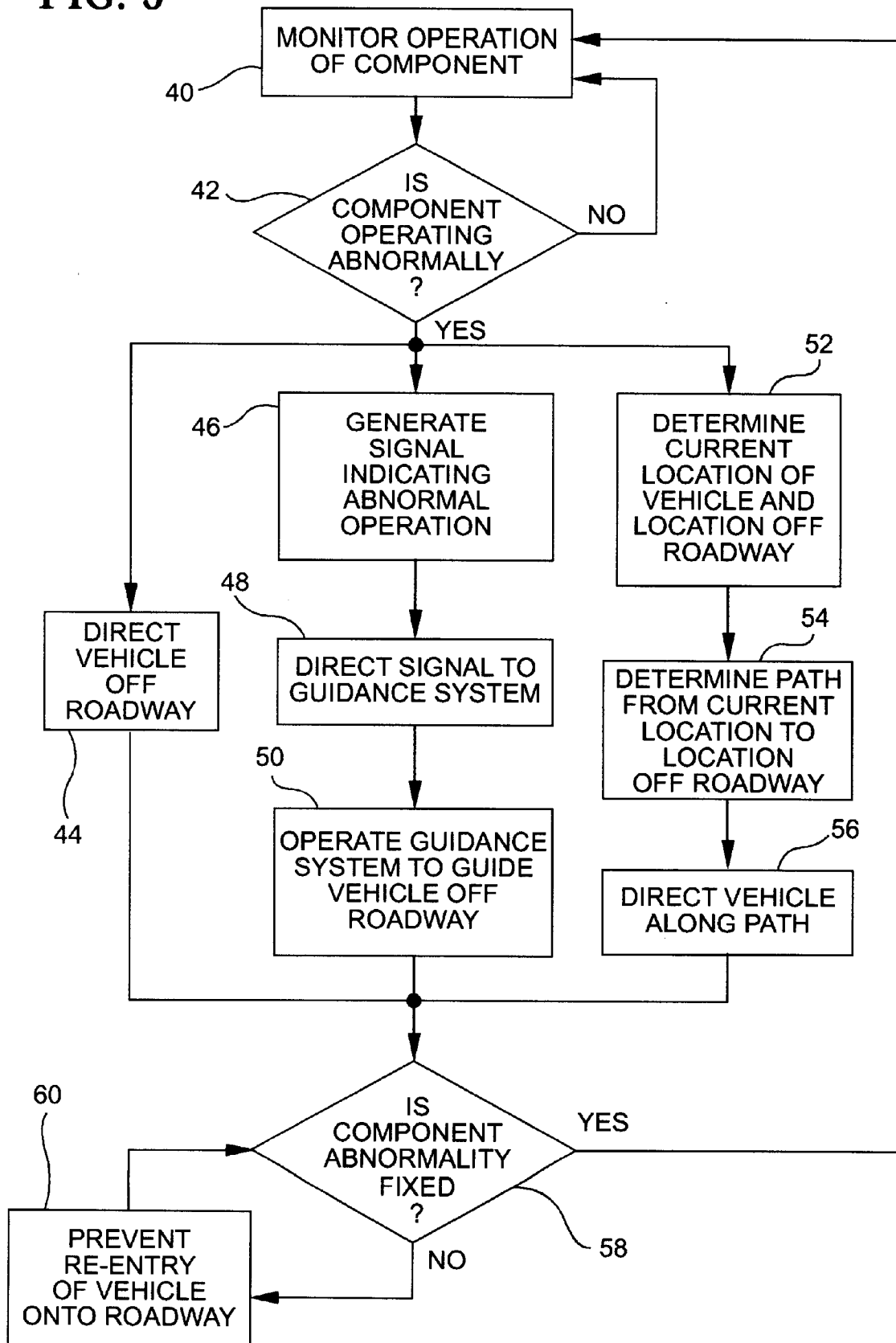


Fig. 4

FIG. 5





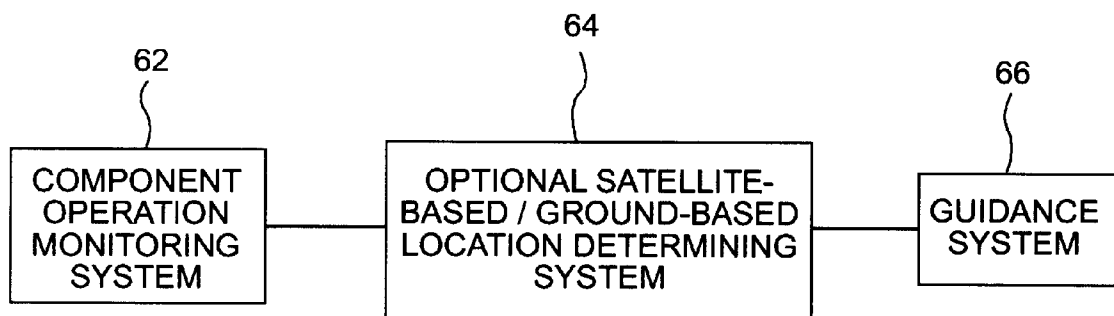
**U.S. Patent**

**Nov. 19, 2002**

**Sheet 6 of 7**

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**FIG. 6**



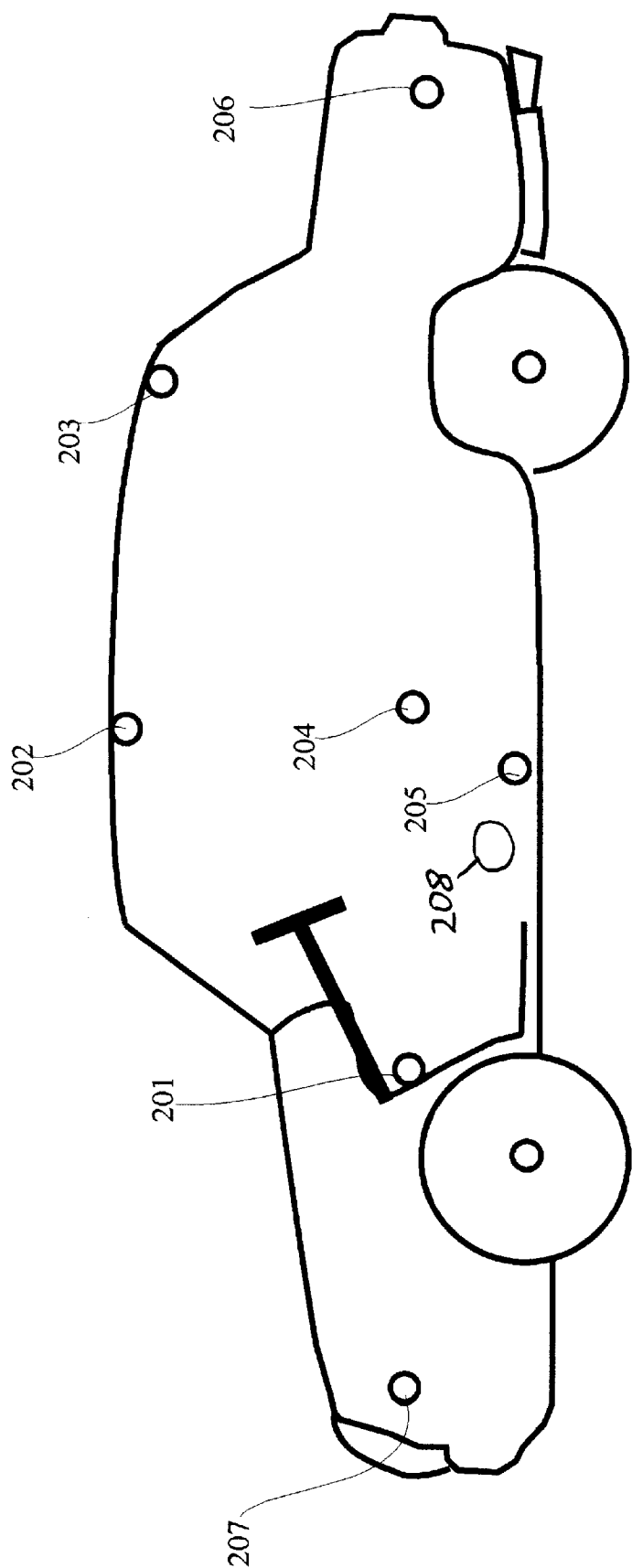


Fig. 7

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## METHOD AND APPARATUS FOR CONTROLLING A VEHICULAR COMPONENT

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 09/137,918 filed Aug. 20, 1998, now U.S. Pat. No. 6,175,787, which is a continuation-in-part of U.S. patent application Ser. No. 08/476,077 filed Jun. 7, 1995, now U.S. Pat. No. 5,809,437.

This application claims priority under 35 U.S.C. §119(e) of U.S. provisional patent application Ser. No. 60/231,378 filed Sep. 8, 2000.

### FIELD OF THE INVENTION

This invention relates to systems and method for diagnosing the state or condition of a vehicle, e.g., whether the vehicle is about to rollover or is experiencing a crash and whether the vehicle has a component which is operating abnormally and could possibly fail resulting in a crash or severe handicap for the operator, and controlling a component of the vehicle in consideration of the diagnosed state or condition of the vehicle.

### BACKGROUND OF THE INVENTION

Every automobile driver fears that his or her vehicle will breakdown at some unfortunate time, e.g., when he or she is traveling at night, during rush hour, or on a long trip away from home. To help alleviate that fear, certain luxury automobile manufacturers provide roadside service in the event of a breakdown. Nevertheless, unless the vehicle is equipped with OnStar or an equivalent service, the vehicle driver must still be able to get to a telephone to call for service. It is also a fact that many people purchase a new automobile out of fear of a breakdown with their current vehicle. This invention is primarily concerned with preventing breakdowns and with minimizing maintenance costs by predicting component failure that would lead to such a breakdown before it occurs.

When a vehicle component begins to fail, the repair cost is frequently minimal if the impending failure of the component is caught early, but increases as the repair is delayed. Sometimes if a component in need of repair is not caught in a timely manner, the component, and particularly the impending failure thereof, can cause other components of the vehicle to deteriorate. One example is where the water pump fails gradually until the vehicle overheats and blows a head gasket. It is desirable, therefore, to determine that a vehicle component is about to fail as early as possible so as to minimize the probability of a breakdown and the resulting repair costs.

There are various gages on an automobile which alert the driver to various vehicle problems. For example, if the oil pressure drops below some predetermined level, the driver is warned to stop his vehicle immediately. Similarly, if the coolant temperature exceeds some predetermined value, the driver is also warned to take immediate corrective action. In these cases, the warning often comes too late as most vehicle gages alert the driver after he or she can conveniently solve the problem. Thus, what is needed is a component failure warning system that alerts the driver to the impending failure of a component sufficiently in advance of the time when the problem gets to a catastrophic point.

Some astute drivers can sense changes in the performance of their vehicle and correctly diagnose that a problem with

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a component is about to occur. Other drivers can sense that their vehicle is performing differently but they don't know why or when a component will fail or how serious that failure will be, or possibly even what specific component is the cause of the difference in performance. The invention disclosed herein will, in most cases, solve this problem by predicting component failures in time to permit maintenance and thus prevent vehicle breakdowns.

Presently, automobile sensors in use are based on specific predetermined or set levels, such as the coolant temperature or oil pressure, whereby an increase above the set level or a decrease below the set level will activate the sensor, rather than being based on changes in this level over time. The rate at which coolant heats up, for example, can be an important clue that some component in the cooling system is about to fail. There are no systems currently on automobiles to monitor the numerous vehicle components over time and to compare component performance with normal performance. Nowhere in the vehicle is the vibration signal of a normally operating front wheel stored, for example, or for that matter, any normal signal from any other vehicle component. Additionally, there is no system currently existing on a vehicle to look for erratic behavior of a vehicle component and to warn the driver or the dealer that a component is misbehaving and is therefore likely to fail in the very near future.

Sometimes, when a component fails, a catastrophic accident results. In the Firestone tire case, for example, over 100 people were killed when a tire of a Ford Explorer blew out which caused the Ford Explorer to rollover. Similarly, other component failures can lead to loss of control of the vehicle and a subsequent accident. It is thus very important to accurately forecast that such an event will take place but furthermore, for those cases where the event takes place suddenly without warning, it is also important to diagnose the state of the entire vehicle, which in some cases can lead to automatic corrective action to prevent unstable vehicle motion or rollovers resulting in an accident. Finally, an accurate diagnostic system for the entire vehicle can determine much more accurately the severity of an automobile crash once it has begun by knowing where the accident is taking place on the vehicle (e.g., the part of or location on the vehicle which is being impacted by an object) and what is colliding with the vehicle based on a knowledge of the force deflection characteristics of the vehicle at that location. Therefore, in addition to a component diagnostic, the teachings of this invention also provide a diagnostic system for the entire vehicle prior to and during accidents. In particular, this invention is concerned with the simultaneous monitoring of multiple sensors on the vehicle so that the best possible determination of the state of the vehicle can be determined. Current crash sensors operate independently or at most one sensor may influence the threshold at which another sensor triggers a deployable restraint. In the teachings of this invention, two or more sensors, frequently accelerometers, are monitored simultaneously and the combination of the outputs of these multiple sensors are combined continuously in making the crash severity analysis.

Marko et al. (U.S. Pat. No. 5,041,976) is directed to a diagnostic system using pattern recognition for electronic automotive control systems and particularly for diagnosing faults in the engine of a motor vehicle after they have occurred. For example, Marko et al. is interested in determining cylinder specific faults after the cylinder is operating abnormally. More specifically, Marko et al. is directed to detecting a fault in a vehicular electromechanical system indirectly, i.e., by means of the measurement of parameters

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of sensors which are affected by that system, and after that fault has already manifested itself in the system. In order to form the fault detecting system, the parameters from these sensors are input to a pattern recognition system for training thereof. Then known faults are introduced and the parameters from the sensors are inputted into the pattern recognition system with an indication of the known fault. Thus, during subsequent operation, the pattern recognition system can determine the fault of the electromechanical system based on the parameters of the sensors, assuming that the fault was "trained" into the pattern recognition system and has already occurred.

When the electromechanical system is an engine, the parameters input into the pattern recognition system for training thereof, and used for fault detection during operation, all relate to the engine. (If the electromechanical system is other than the engine, then the parameters input into the pattern recognition system would relate to that system.) In other words, each parameter will be affected by the operation of the engine and depend thereon and changes in the operation of the engine will alter the parameter, e.g., the manifold absolute pressure is an indication of the airflow into the engine. In this case, the signal from the manifold absolute pressure sensor may be indicative of a fault in the intake of air into the engine, e.g., the engine is drawing in too much or too little air, and is thus affected by the operation of the engine. Similarly, the mass air flow is the airflow into the engine and is an alternative to the manifold absolute pressure. It is thus a parameter that is directly associated with, related to and dependent on the engine. The exhaust gas oxygen sensor is also affected by the operation of the engine, and thus directly associated therewith, since during normal operation, the mixture of the exhaust gas is neither rich or lean whereas during abnormal engine operation, the sensor will detect an abrupt change indicative of the mixture being too rich or too lean.

Thus, the system of Marko et al. is based on the measurement of sensors which affect or are affected by, i.e., are directly, associated with, the operation of the electromechanical system for which faults are to be detected. However, the system of Marko et al. does not detect faults in the sensors that are conducting the measurements, e.g., a fault in the exhaust gas oxygen sensor, or faults that are only developing but have not yet manifested themselves or faults in other systems. Rather, the sensors are used to detect a fault in the system after it has occurred.

Asami et al. (U.S. Pat. No. 4,817,418) is directed to a failure diagnosis system for a vehicle including a failure display means for displaying failure information to a driver. This system only reports failures after they have occurred and does not predict them.

Tiernan et al. (U.S. Pat. No. 5,313,407) is directed, inter alia, to a system for providing an exhaust active noise control system, i.e., an electronic muffler system, including an input microphone 60 which senses exhaust noise at a first location 61 in an exhaust duct 58. An engine has exhaust manifolds 56, 57 feeding exhaust air to the exhaust duct 58. The exhaust noise sensed by the microphone 60 is processed to obtain an output from an output speaker 65 arranged downstream of the input microphone 61 in the exhaust path in order to cancel the noise in the exhaust duct 58.

Scholl et al. (U.S. Pat. No. 5,400,018) is directed to a method for relaying information relating to the status of a vehicle to a remote location over a communications data link.

Haramaty et al. (U.S. Pat. No. 5,406,502) describes a system that monitors a machine in a factory and notifies

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maintenance personnel remote from the machine (not the machine operator) that maintenance should be scheduled at a time when the machine is not in use. Haramaty et al. does not expressly relate to vehicular applications.

NASA Technical Support Package MFS-26529 "Engine Monitoring Based on Normalized Vibration Spectra", describes a technique for diagnosing engine health using a neural network based system and is incorporated by reference herein in its entirety.

A paper "Using acoustic emission signals for monitoring of production processes" by H. K. Tonshoff et al. also provides a good description of how acoustic signals can be used to predict the state of machine tools and is incorporated by reference herein in its entirety.

Preferred embodiments of the invention are described below and unless specifically noted, it is the applicant's intention that the words and phrases in the specification and claims be given the ordinary and accustomed meaning to those of ordinary skill in the applicable art(s). If applicant intends any other meaning, he will specifically state they are applying a special meaning to a word or phrase.

Likewise, applicant's use of the word "function" here is not intended to indicate that the applicant seeks to invoke the special provisions of 35 U.S.C. §112, sixth paragraph, to define their invention. To the contrary, if applicant wishes to invoke the provisions of 35 U.S.C. §112, sixth paragraph, to define their invention, he will specifically, set forth in the claims the phrases "means for" or "step for" and a function, without also reciting in that phrase any structure, material or act in support of the function. Moreover, even if applicant invokes the provisions of 35 U.S.C. §112, sixth paragraph, to define his invention, it is the applicant's intention that his inventions not be limited to the specific structure, material or acts that are described in the preferred embodiments herein. Rather, if applicant claims his inventions by specifically invoking the provisions of 35 U.S.C. §112, sixth paragraph, it is nonetheless his intention to cover and include any and all structure, materials or acts that perform the claimed function, along with any and all known or later developed equivalent structures, materials or acts for performing the claimed function.

#### OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to solve the above problems by monitoring the patterns of signals emitted from the vehicle components and, through the use of pattern recognition technology, forecasting component failures before they occur. Vehicle component behavior is monitored over time in contrast to currently used systems that merely wait until a serious condition occurs. It is another object of the present invention to provide a new and improved on-board vehicle diagnostic module utilizing pattern recognition technologies which are trained to differentiate normal from abnormal component behavior. In this manner, the problems discussed above, as well as many others, are alleviated by the vehicle diagnostic module described in the paragraphs below.

It is yet another object of the present invention to provide a diagnostic module that determines whether a component is operating normally or abnormally based on a time series of data from a single sensor or from multiple sensors that contain a pattern indicative of the operating status of the component.

It is still another object of the present invention to provide a diagnostic module that determines whether a component is

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operating normally or abnormally based on data from one or more sensors that are not directly associated with the component, i.e., do not depend on the operation of the component.

It is an additional object of the present invention to simultaneously monitor several sensors, primarily accelerometers, gyroscopes and strain gages, to determine the state of the vehicle and optionally its occupants and to determine that a vehicle is out of control and possibly headed for an accident, for example. If so, then a signal can be sent to a part of the vehicle control system to attempt to re-establish stability. If this is unsuccessful, then the same system of sensors can monitor the early stages of a crash to make an assessment of the severity of the crash and what occupant protection systems should be deployed and how such occupant protection systems should be deployed.

The diagnostic module in accordance with the invention utilizes information which already exists in signals emanating from various vehicle components along with sensors which sense these signals and, using pattern recognition techniques, compares these signals with patterns characteristic of normal and abnormal component performance to predict component failure, vehicle instability or a crash earlier than would otherwise occur if the diagnostic module was not utilized. If fully implemented, this invention is a total diagnostic system of the vehicle. In most implementations, the module is attached to the vehicle and electrically connected to the vehicle data bus where it analyzes data appearing on the bus to diagnose components of the vehicle. In some implementations, multiple distributed accelerometers and/or microphones are present on the vehicle and, in some cases, some of the sensors will communicate using wireless technology to the vehicle bus or directly to the diagnostic module.

Principal objects and advantages of this invention are thus:

1. To prevent vehicle breakdowns.
2. To alert the driver of the vehicle that a component of the vehicle is functioning differently than normal and might be in danger of failing.
3. To alert the dealer, or other repair facility, that a component of the vehicle is functioning differently than normal and is in danger of failing.
4. To provide an early warning of a potential component failure and to thereby minimize the cost of repairing or replacing the component.
5. To provide a device which will capture available information from signals emanating from vehicle components for a variety of uses such as current and future vehicle diagnostic purposes.
6. To provide a device that uses information from existing sensors for new purposes thereby increasing the value of existing sensors and, in some cases, eliminating the need for sensors that provide redundant information.
7. To provide a device which is trained to recognize deterioration in the performance of a vehicle component, or of the entire vehicle, based on information in signals emanating from the component or from vehicle angular and linear accelerations.
8. To provide a device which analyzes vibrations from various vehicle components that are transmitted through the vehicle structure and sensed by existing vibration sensors such as vehicular crash sensors used with airbag systems or by special vibration sensors, accelerometers, or gyroscopes.

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9. To provide a device which provides information to the vehicle manufacturer of the events leading to a component failure.
10. To apply pattern recognition techniques based on training to diagnosing potential vehicle component failures.
11. To apply component diagnostic techniques in combination with intelligent or smart highways wherein vehicles may be automatically guided without manual control in order to permit the orderly exiting of the vehicle from a restricted roadway prior to a breakdown of the vehicle.
12. To apply trained pattern recognition techniques using multiple sensors to provide an early prediction of the existence and severity of an accident.
13. To utilize pattern recognition techniques and the output from multiple sensors to determine at an early stage that a vehicle rollover might occur and to take corrective action through control of the vehicle acceleration, brakes and steering to prevent the rollover or if it is preventable, to deploy side head protection airbags to reduce the injuries.
14. To use the output from multiple sensors to determine that the vehicle is skidding or sliding and to send messages to the various vehicle control systems to activate the throttle, brakes and/or steering to correct for the vehicle sliding or skidding motion.

Other objects and advantages of the present invention will become apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawings.

#### SUMMARY OF THE INVENTION

Accordingly, in one embodiment of the invention, the state of the entire vehicle is diagnosed whereby two or more sensors, preferably acceleration sensors and gyroscopes, detect the state of the vehicle and if the state is abnormal, output means are coupled to the processor means for affecting another system in the vehicle. The another system may be the steering control system, the brake system, the accelerator or the frontal or side occupant protection system. An exemplifying control system for controlling a part of the vehicle in accordance with the invention thus comprises a plurality of sensor systems mounted at different locations on the vehicle, each sensor system providing a measurement related to a state of the sensor system or a measurement related to a state of the mounting location, and a processor coupled to the sensor systems and arranged to diagnose the state of the vehicle based on the measurements of the sensor system, e.g., by the application of a pattern recognition technique. The processor controls the part based at least in part on the diagnosed state of the vehicle. At least one of the sensor systems may be a high dynamic range accelerometer or a sensor selected from a group consisting of a single axis acceleration sensor, a double axis acceleration sensor, a triaxial acceleration sensor and a gyroscope, and may optionally include an RFID response unit. The gyroscope may be a MEMS-IDT gyroscope including a surface acoustic wave resonator which applies standing waves on a piezoelectric substrate. If an RFID response unit is present, the control system would then comprise an RFID interrogator device which causes the RFID response unit(s) to transmit a signal representative of the measurement of the sensor system associated therewith to the processor.

The state of the vehicle diagnosed by the processor may be the vehicle's angular motion, angular acceleration and/or



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angular velocity. As such, the steering system, braking system or throttle system may be controlled by the processor in order to maintain the stability of the vehicle. The processor can also be arranged to control an occupant restraint or protection device in an attempt to minimize injury to an occupant.

The state of the vehicle diagnosed by the processor may also be a determination of a location of an impact between the vehicle and another object. In this case, the processor can forecast the severity of the impact using the force/crush properties of the vehicle at the impact location and control an occupant restraint or protection device based at least in part on the severity of the impact.

The system can also include a weight sensing system coupled to a seat in the vehicle for sensing the weight of an occupying item of the seat. The weight sensing system is coupled to the processor whereby the processor controls deployment or actuation of the occupant restraint or protection device based on the state of the vehicle and the weight of the occupying item of the seat sensed by the weight sensing system.

A display may be coupled to the processor for displaying an indication of the state of the vehicle as diagnosed by the processor. A warning device may be coupled to the processor for relaying a warning to an occupant of the vehicle relating to the state of the vehicle as diagnosed by the processor. Further, a transmission device may be coupled to the processor for transmitting a signal to a remote site relating to the state of the vehicle as diagnosed by the processor.

The state of the vehicle diagnosed by the processor may include angular acceleration of the vehicle whereby angular velocity and angular position or orientation are derivable from the angular acceleration. The processor can then be arranged to control the vehicle's navigation system based on the angular acceleration of the vehicle.

A method for controlling a part of the vehicle in accordance with the invention comprises the step of mounting a plurality of sensor systems at different locations on the vehicle, measuring a state of the sensor system or a state of the respective mounting location of the sensor system, diagnosing the state of the vehicle based on the measurements of the state of the sensor systems or the state of the mounting locations of the sensor systems, and controlling the part based at least in part on the diagnosed state of the vehicle. The state of the sensor system may be any one or more of the acceleration, angular acceleration, angular velocity or angular orientation of the sensor system. Diagnosis of the state of the vehicle may entail determining whether the vehicle is stable or is about to rollover or skid and/or determining a location of an impact between the vehicle and another object. Diagnosis of the state of the vehicle may also entail determining angular acceleration of the vehicle based on the acceleration measured by accelerometers if multiple accelerometers are present as the sensor systems.

Another control system for controlling a part of the vehicle in accordance with the invention comprises a plurality of sensor systems mounted on the vehicle, each providing a measurement of a state of the sensor system or a state of the mounting location of the sensor system and generating a signal representative of the measurement, and a pattern recognition system for receiving the signals from the sensor systems and diagnosing the state of the vehicle based on the measurements of the sensor systems. The pattern recognition system generates a control signal for controlling the part based at least in part on the diagnosed

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state of the vehicle. The pattern recognition system may comprise one or more neural networks. The features of the control system described above may also be incorporated into this control system to the extent feasible.

The state of the vehicle diagnosed by the pattern recognition system may include a state of an abnormally operating component whereby the pattern recognition system is designed to identify, a potentially malfunctioning component based on the state of the component measured by the sensor systems and determine whether the identified component is operating abnormally based on the state of the component measured by the sensor systems.

In one preferred embodiment, the pattern recognition system may comprise a neural network system and the state of the vehicle diagnosed by the neural network system includes a state of an abnormally operating component. The neural network system includes a first neural network for identifying a potentially malfunctioning component based on the state of the component measured by the sensor systems and a second neural network for determining whether the identified component is operating abnormally based on the state of the component measured by the sensor systems.

Modular neural networks can also be used whereby the neural network system includes a first neural network arranged to identify, a potentially malfunctioning component based on the state of the component measured by the sensor systems and a plurality of additional neural networks. Each of the additional neural networks is trained to determine whether a specific component is operating abnormally so that the measurements of the state of the component from the sensor systems are input into that one of the additional neural networks trained on a component which is substantially identical to the identified component.

Another method for controlling a part of the vehicle comprises the steps of mounting a plurality of sensor systems on the vehicle, measuring a state of the sensor system or a state of the respective mounting location of the sensor system, generating signals representative of the measurements of the sensor systems, inputting the signals into a pattern recognition system to obtain a diagnosis of the state of the vehicle and controlling the part based at least in part on the diagnosis of the state of the vehicle.

In one notable embodiment, a potentially malfunctioning component is identified by the pattern recognition system based on the states measured by the sensor systems and the pattern recognition system determine whether the identified component is operating abnormally based on the states measured by the sensor systems. If the pattern recognition system comprises a neural network system, identification of the component entails inputting the states measured by the sensor systems into a first neural network of the neural network system and the determination of whether the identified component is operating abnormally entails inputting the states measured by the sensor systems into a second neural network of the neural network system. A modular neural network system can also be applied in which the states measured by the sensor systems are input into a first neural network and a plurality of additional neural networks are provided, each being trained to determine whether a specific component is operating abnormally, whereby the states measured by the sensor systems are input into that one of the additional neural networks trained on a component which is substantially identical to the identified component.

Another control system for controlling a part of the vehicle based on occupancy of the seat in accordance with

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the invention comprises a plurality of strain gages mounted in connection with the seat, each measuring strain of a respective mounting location caused by occupancy of the seat, and a processor coupled to the strain gages and arranged to determine the weight of an occupying item based on the strain measurements from the strain gages over a period of time, i.e., dynamic measurements. The processor controls the part based at least in part on the determined weight of the occupying item of the seat. The processor can also determine motion of the occupying item of the seat based on the strain measurements from the strain gages over the period of time. One or more accelerometers may be mounted on the vehicle for measuring acceleration in which case, the processor may control the part based at least in part on the determined weight of the occupying item of the seat and the acceleration measured by the accelerometer(s).

By comparing the output of various sensors in the vehicle, it is possible to determine activities that are affecting parts of the vehicle while not affecting other parts. For example, by monitoring the vertical accelerations of various parts of the vehicle and comparing these accelerations with the output of strain gage load cells placed on the seat support structure, a characterization can be made of the occupancy of the seat. Not only can the weight of an object occupying the seat be determined, but also the gross motion of such an object can be ascertained and thereby an assessment can be made as to whether the object is a life form such as a human being. Strain gage weight sensors are disclosed in co-pending U.S. patent application Ser. No. 09/193,209 filed Nov. 17, 1998 (corresponding to International Publication No. WO 00/29257), which is included in here in its entirety as if the entire application were printed herein, by reference. In particular, the inventors contemplate the combination of all of the ideas expressed in this patent application with those expressed in the current invention.

As used herein, a diagnosis of the "state of the vehicle" means a diagnosis of the condition of the vehicle with respect to its stability and proper running and operating condition. Thus, the state of the vehicle could be normal when the vehicle is operating properly on a highway or abnormal when, for example, the vehicle is experiencing excessive angular inclination (e.g., two wheels are off the ground and the vehicle is about to rollover), the vehicle is experiencing a crash, the vehicle is skidding, and other similar situations. A diagnosis of the state of the vehicle could also be an indication that one of the parts of the vehicle, e.g., a component, system or subsystem, is operating abnormally.

As used herein, an "occupant restraint device" includes any type of device which is deployable in the event of a crash involving the vehicle for the purpose of protecting an occupant from the effects of the crash and/or minimizing the potential injury to the occupant. Occupant restraint devices thus include frontal airbags, side airbags, seatbelt tensioners, knee bolsters, side curtain airbags, externally deployable airbags and the like.

As used herein, a "part" of the vehicle includes any component, sensor, system or subsystem of the vehicle such as the steering system, braking system, throttle system, navigation system, airbag system, seatbelt retractor, air bag inflation valve, air bag inflation controller and airbag vent valve, as well as those listed below in the definitions of "component" and "sensor".

As used herein, a "sensor system" includes any of the sensors listed below in the definition of "sensor" as well as any type of component or assembly of components which detect, sense or measure something.

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## BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings are illustrative of embodiments of the invention and are not meant to limit the scope of the invention as encompassed by the claims.

FIG. 1 is a schematic illustration of a generalized component with several signals being emitted and transmitted along a variety of paths, sensed by a variety of sensors and analyzed by the diagnostic module in accordance with the invention and for use in a method in accordance with the invention.

FIG. 2 is a schematic of one pattern recognition methodology known as a neural network which may be used in a method in accordance with the invention.

FIG. 3 is a schematic of a vehicle with several components and several sensors and a total vehicle diagnostic system in accordance with the invention utilizing a diagnostic module in accordance with the invention and which may be used in a method in accordance with the invention.

FIG. 4 is a flow diagram of information flowing from various sensors onto the vehicle data bus and thereby into the diagnostic module in accordance with the invention with outputs to a display for notifying the driver, and to the vehicle cellular phone for notifying another person, of a potential component failure.

FIG. 5 is a flow chart of the methods for automatically monitoring a vehicular component in accordance with the invention.

FIG. 6 is a schematic illustration of the components used in the methods for automatically monitoring a vehicular component.

FIG. 7 is a schematic of a vehicle with several accelerometers and/or gyroscopes at preferred locations in the vehicle.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purposes herein the following terms are defined as follows:

The term "component" refers to any part or assembly of parts which is mounted to or a part of a motor vehicle and which is capable of emitting a signal representative of its operating state. The following is a partial list of general automobile and truck components, the list not being exclusive:

- engine;
- transmission;
- brakes and associated brake assembly;
- tires;
- wheel;
- steering wheel and steering column assembly;
- water pump;
- alternator;
- shock absorber;
- wheel mounting assembly;
- radiator;
- battery;
- oil pump;
- fuel pump;
- air conditioner compressor;
- differential gear;
- exhaust system;

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fan belts;  
 engine valves;  
 steering assembly;  
 vehicle suspension including shock absorbers;  
 vehicle wiring system; and  
 engine cooling fan assembly.

The term "sensor" refers to any measuring or sensing device mounted on a vehicle or any of its components including new sensors mounted in conjunction with the diagnostic module in accordance with the invention. A partial, non-exclusive list of common sensors mounted on an automobile or truck is as follows:

airbag crash sensor;  
 accelerometer;  
 microphone;  
 camera;  
 antenna, capacitance sensor or other electromagnetic wave sensor;  
 stress or strain sensor;  
 pressure sensor;  
 weight sensor;  
 magnetic field sensor;  
 coolant thermometer;  
 oil pressure sensor;  
 oil level sensor;  
 air flow meter;  
 voltmeter;  
 ammeter;  
 humidity sensor;  
 engine knock sensor;  
 oil turbidity sensor;  
 throttle position sensor;  
 steering-wheel torque sensor;  
 wheel speed sensor;  
 tachometer;  
 speedometer;  
 other velocity sensors;  
 other position or displacement sensors;  
 oxygen sensor;  
 yaw, pitch and roll angular sensors;  
 clock;  
 odometer;  
 power steering pressure sensor;  
 pollution sensor;  
 fuel gauge;  
 cabin thermometer;  
 transmission fluid level sensor;  
 gyroscopes or other angular rate sensors including yaw, pitch and roll rate sensors;  
 coolant level sensor;  
 transmission fluid turbidity sensor;  
 break pressure sensor;  
 tire pressure sensor;  
 tire temperature sensor, and  
 coolant pressure sensor.

The term "signal" herein refers to any time varying output from a component including electrical, acoustic, thermal, or electromagnetic radiation, or mechanical vibration.

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Sensors on a vehicle are generally designed to measure particular parameters of particular vehicle components. However, frequently these sensors also measure outputs from other vehicle components. For example, electronic airbag crash sensors currently in use contain an accelerometer for determining the accelerations of the vehicle structure so that the associated electronic circuitry of the airbag crash sensor can determine whether a vehicle is experiencing a crash of sufficient magnitude so as to require deployment of the airbag. This accelerometer continuously monitors the vibrations in the vehicle structure regardless of the source of these vibrations. If a wheel is out of balance, or if there is extensive wear of the parts of the front wheel mounting assembly, or wear in the shock absorbers, the resulting abnormal vibrations or accelerations can, in many cases, be sensed by the crash sensor accelerometer. There are other cases, however, where the sensitivity or location of the airbag crash sensor accelerometer is not appropriate and one or more additional accelerometers may be mounted onto a vehicle for the purposes of this invention. Some airbag crash sensors are not sufficiently sensitive accelerometers or have sufficient dynamic range for the purposes herein.

Every component of a vehicle emits various signals during its life. These signals can take the form of electromagnetic radiation, acoustic radiation, thermal radiation, vibrations transmitted through the vehicle structure, and voltage or current fluctuations, depending on the particular component. When a component is functioning normally, it may not emit a perceptible signal. In that case, the normal signal is no signal, i.e., the absence of a signal. In most cases, a component will emit signals that change over its life and it is these changes which contain information as to the state of the component, e.g., whether failure of the component is impending. Usually components do not fail without warning. However, most such warnings are either not perceived or if perceived are not understood by the vehicle operator until the component actually fails and, in some cases, a breakdown of the vehicle occurs. In a few years, it is expected that various roadways will have systems for automatically guiding vehicles operating thereon. Such systems have been called "smart highways" and are part of the field of intelligent transportation systems (ITS). If a vehicle operating on such a smart highway were to breakdown, serious disruption of the system could result and the safety of other users of the smart highway could be endangered.

In accordance with the invention, each of these signals emitted by the vehicle components is converted into electrical signals and then digitized (i.e., the analog signal is converted into a digital signal) to create numerical time series data which is then entered into a processor. Pattern recognition algorithms then are applied in the processor to attempt to identify and classify patterns in this time series data. For a particular component, such as a tire for example, the algorithm attempts to determine from the relevant digital data whether the tire is functioning properly or whether it requires balancing, additional air, or perhaps replacement.

Frequently, the data entered into the computer needs to be preprocessed before being analyzed by a pattern recognition algorithm. The data from a wheel speed sensor, for example, might be used as is for determining whether a particular tire is operating abnormally in the event it is unbalanced, whereas the integral of the wheel speed data over a long time period (a preprocessing step), when compared to such sensors on different wheels, might be more useful in determining whether a particular tire is going flat and therefore needs air. In some cases, the frequencies present in a set of data are a better predictor of component failures than the data itself.



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For example, when a motor begins to fail due to worn bearings, certain characteristic frequencies began to appear. In most cases, the vibrations arising from rotating components, such as the engine, will be normalized based on the rotational frequency as disclosed in the NASA TSP 5 referenced above. Moreover, the identification of which component is causing vibrations present in the vehicle structure can frequently be accomplished through a frequency analysis of the data. For these cases, a Fourier transformation of the data is made prior to entry of the data into a pattern recognition algorithm. Other mathematical transformations are also made for particular pattern recognition purposes in practicing the teachings of this invention. Some of these include shifting and combining data to determine phase changes for example, differentiating the data, filtering the data, and sampling the data. Also, there exist certain more sophisticated mathematical operations that attempt to extract or highlight specific features of the data. This invention contemplates the use of a variety of these preprocessing techniques and the choice of which ones is left to the skill of the practitioner designing a particular diagnostic module.

Another technique that is contemplated for some implementations of this invention is the use of multiple accelerometers and/or microphones that will allow the system to locate the source of any measured vibrations based on the time of flight and/or triangulation techniques. Once a distributed accelerometer installation has been implemented to permit this source location, the same sensors can be used for smarter crash sensing as it will permit the determination of the location of the impact on the vehicle. Once the impact location is known, a highly tailored algorithm can be used to accurately forecast the crash severity making use of a knowledge on the force vs. crush properties of the vehicle at the impact location.

When a vehicle component begins to change its operating behavior, it is not always apparent from the particular sensors, if any, which are monitoring that component. The output from any one of these sensors can be normal even though the component is failing. By analyzing the output of a variety of sensors, however, the pending failure can be diagnosed. For example, the rate of temperature rise in the vehicle coolant, if it were monitored, might appear normal unless it were known that the vehicle was idling and not traveling down a highway at a high speed. Even the level of coolant temperature which is in the normal range could be in fact abnormal in some situations signifying a failing coolant pump, for example, but not detectable from the coolant thermometer alone.

The pending failure of some components is difficult to diagnose and sometimes the design of the component requires modification so that the diagnosis can be more readily made. A fan belt, for example, frequently begins failing by a cracking of the inner surface. The belt can be designed to provide a sonic or electrical signal when this cracking begins in a variety of ways. Similarly, coolant hoses can be designed with an intentional weak spot where failure will occur first in a controlled manner that can also cause a whistle sound as a small amount of steam exits from the hose. This whistle sound can then be sensed by a general purpose microphone, for example.

In FIG. 1, a generalized component 100 emitting several signals which are transmitted along a variety of paths, sensed by a variety of sensors and analyzed by the diagnostic device, in accordance with the invention is illustrated schematically. Component 100 is mounted to a vehicle 180 and during operation it emits a variety of signals such as acoustic

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101, electromagnetic radiation 102, thermal radiation 103, current and voltage fluctuations in conductor 104 and mechanical vibrations 105. Various sensors are mounted in the vehicle to detect the signals emitted by the component 100. These include one or more vibration sensors (accelerometers) 130, 150 and/or gyroscopes also mounted to the vehicle, one or more acoustic sensors 110, 151, electromagnetic radiation sensor 115, heat radiation sensor 120, and voltage or current sensor 140. In addition, various other sensors 152, 153 measure other parameters of other components that in some manner provide information directly or indirectly on the operation of component 100. All of the sensors illustrated on FIG. 1 can be connected to a data bus 160. A diagnostic module 170, in accordance with the invention, can also be attached to the vehicle data bus 160 and receives the signals generated by the various sensors. The sensors may however be wirelessly connected to the diagnostic module 170 and be integrated into a wireless power and communications system or a combination of wired and wireless connections.

As shown in FIG. 1, the diagnostic module 170 has access to the output data of each of the sensors that have information relative to the component 100. This data appears as a series of numerical values each corresponding to a measured value at a specific point in time. The cumulative data from a particular sensor is called a time series of individual data points. The diagnostic module 170 compares the patterns of data received from each sensor individually, or in combination with data from other sensors, with patterns for which the diagnostic module has been trained to determine whether the component is functioning normally or abnormally.

Central to this invention are the manner in which the diagnostic module 170 determines a normal pattern from an abnormal pattern and the manner in which it decides what data to use from the vast amount of data available. This is accomplished using pattern recognition technologies such as artificial neural networks and training. The theory of neural networks including many examples can be found in several books on the subject including: *Techniques And Application Of Neural Networks*, edited by Taylor, M. and Lisboa, P., Ellis Horwood, West Sussex, England, 1993; *Naturally Intelligent Systems*, by Caudill, M. and Butler, C., MIT Press, Cambridge, Mass., 1990; J. M. Zaruda, *Introduction to Artificial Neural Systems*, West publishing Co., N.Y., 1992 and, *Digital Neural Networks*, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, N.J., 1993, all of which are included herein by reference. The neural network pattern recognition technology is one of the most developed of pattern recognition technologies. The neural network will be used here to illustrate one example of a pattern recognition technology but it is emphasized that this invention is not limited to neural networks. Rather, the invention may apply any known pattern recognition technology including sensor fusion and various correlation technologies. A brief description of the neural network pattern recognition technology is set forth below.

Neural networks are constructed of processing elements known as neurons that are interconnected using information channels call interconnects. Each neuron can have multiple inputs but only one output. Each output however is usually connected to all other neurons in the next layer. The neurons in the first layer operate collectively on the input data as described in more detail below. Neural networks learn by extracting relational information from the data and the desired output. Neural networks have been applied to a wide variety of pattern recognition problems including automobile occupant sensing, speech recognition, optical character recognition, and handwriting analysis.

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To train a neural network, data is provided in the form of one or more time series that represents the condition to be diagnosed as well as normal operation. As an example, the simple case of an out of balance tire will be used. Various sensors on the vehicle can be used to extract information from signals emitted by the tire such as an accelerometer, a torque sensor on the steering wheel, the pressure output of the power steering system, a tire pressure monitor or tire temperature monitor. Other sensors that might not have an obvious relationship to tire unbalance are also included such as, for example, the vehicle speed or wheel speed. Data is taken from a variety of vehicles where the tires were accurately balanced under a variety of operating conditions also for cases where varying amounts of unbalance was intentionally introduced. Once the data had been collected, some degree of preprocessing or feature extraction is usually performed to reduce the total amount of data fed to the neural network. In the case of the unbalanced tire, the time period between data points might be chosen such that there are at least ten data points per revolution of the wheel. For some other application, the time period might be one minute or one millisecond.

Once the data has been collected, it is processed by a neural network-generating program, for example, if a neural network pattern recognition system is to be used. Such programs are available commercially, e.g., from NeuralWare of Pittsburgh, Pa. The program proceeds in a trial and error manner until it successfully associates the various patterns representative of abnormal behavior, an unbalanced tire, with that condition. The resulting neural network can be tested to determine if some of the input data from some of the sensors, for example, can be eliminated. In this way, the engineer can determine what sensor data is relevant to a particular diagnostic problem. The program then generates an algorithm that is programmed onto a microprocessor, microcontroller, neural processor, or DSP (herein collectively referred to as a microprocessor or processor). Such a microprocessor appears inside the diagnostic module 170 in FIG. 1. Once trained, the neural network, as represented by the algorithm, will now recognize an unbalanced tire on a vehicle when this event occurs. At that time, when the tire is unbalanced, the diagnostic module 170 will output a message to the driver indicating that the tire should be now be balanced as described in more detail below. The message to the driver is provided by output means coupled to or incorporated within the module 170 and may be, e.g., a light on the dashboard, a vocal tone or any other recognizable indication apparatus.

It is important to note that there may be many neural networks involved in a total vehicle diagnostic system. These can be organized either in parallel, series, as an ensemble, cellular neural network or as a modular neural network system. In one implementation of a modular neural network, a primary neural network identifies that there is an abnormality and tries to identify the likely source. Once a choice has been made as to the likely source of the abnormality, another of a group of neural networks is called upon to determine the exact cause of the abnormality. In this manner, the neural networks are arranged in a tree pattern with each neural network trained to perform a particular pattern recognition task.

Discussions on the operation of a neural network can be found in the above references on the subject and are well understood by those skilled in the art. Neural networks are the most well known of the pattern recognition technologies based on training, although neural networks have only recently received widespread attention and have been

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applied to only very limited and specialized problems in motor vehicles. Other non-training based pattern recognition technologies exist, such as fuzzy logic. However, the programming required to use fuzzy logic, where the patterns must be determined by the programmer, render these systems impractical for general vehicle diagnostic problems such as described herein. Therefore, preferably the pattern recognition systems that learn by training are used herein.

The neural network is the first highly successful of what will be a variety of pattern recognition techniques based on training. There is nothing that suggests that it is the only or even the best technology. The characteristics of all of these technologies which render them applicable to this general diagnostic problem include the use of time-based input data and that they are trainable. In all cases, the pattern recognition technology learns from examples of data characteristic of normal and abnormal component operation.

A diagram of one example of a neural network used for diagnosing an unbalanced tire, for example, based on the teachings of this invention is shown in FIG. 2. The process can be programmed to periodically test for an unbalanced tire. Since this need be done only infrequently, the same processor can be used for many such diagnostic problems. When the particular diagnostic test is run, data from the previously determined relevant sensors is preprocessed and analyzed with the neural network algorithm. For the unbalanced tire, using the data from an accelerometer for example, the digital acceleration values from the analog to digital converter in the accelerometer are entered into nodes 1 through n and the neural network algorithm compares the pattern of values on nodes 1 through n with patterns for which it has been trained as follows.

Each of the input nodes is connected to each of the second layer nodes, h-1, h-2, . . . , h-n, called the hidden layer, either electrically as in the case of a neural computer, or through mathematical functions containing multiplying coefficients called weights, in the manner described in more detail in the above references. At each hidden layer node, a summation occurs of the values from each of the input layer nodes, which have been operated on by functions containing the weights, to create a node value. Similarly, the hidden layer nodes are in like manner connected to the output layer node(s), which in this example is only a single node 0 representing the decision to notify the driver of the unbalanced tire. During the training phase, an output node value of 1, for example, is assigned to indicate that the driver should be notified and a value of 0 is assigned to not doing so. Once again, the details of this process are described in above-referenced texts and will not be presented in detail here.

In the example above, twenty input nodes were used, five hidden layer nodes and one output layer node. In this example, only one sensor was considered and accelerations from only one direction were used. If other data from other sensors such as accelerations from the vertical or lateral directions were also used, then the number of input layer nodes would increase. Again, the theory for determining the complexity of a neural network for a particular application has been the subject of many technical papers and will not be presented in detail here. Determining the requisite complexity for the example presented here can be accomplished by those skilled in the art of neural network design.

Briefly, the neural network described above defines a method, using a pattern recognition system, of sensing an unbalanced tire and determining whether to notify the driver and comprises the steps of:

- (a) obtaining an acceleration signal from an accelerometer mounted on a vehicle,

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- (b) converting the acceleration signal into a digital time series.
- (c) entering the digital time series data into the input nodes of the neural network;
- (d) performing a mathematical operation on the data from each of the input nodes and inputting the operated on data into a second series of nodes wherein the operation performed on each of the input node data prior to inputting the operated on value to a second series node is different from that operation performed on some other input node data;
- (e) combining the operated on data from all of the input nodes into each second series node to form a value at each second series node;
- (f) performing a mathematical operation on each of the values on the second series of nodes and inputting this operated on data into an output series of nodes wherein the operation performed on each of the second series node data prior to inputting the operated on value to an output series node is different from that operation performed on some other second series node data;
- (g) combining the operated on data from all of the second series nodes into each output series node to form a value at each output series node; and;
- (h) notifying a driver if the value on one output series node is within a chosen range signifying that a tire requires balancing.

This method can be generalized to a method of predicting that a component of a vehicle will fail comprising the steps of:

- (a) sensing a signal emitted from the component;
- (b) converting the sensed signal into a digital time series;
- (c) entering the digital time series data into a pattern recognition algorithm;
- (d) executing the pattern recognition algorithm to determine if there exists within the digital time series data a pattern characteristic of abnormal operation of the component; and
- (e) notifying a driver if the abnormal pattern is recognized.

The particular neural network described and illustrated above contains a single series of hidden layer nodes. In some network designs, more than one hidden layer is used, although only rarely will more than two such layers appear. There are of course many other variations of the neural network architecture illustrated above which appear in the referenced literature. For the purposes herein, therefore, "neural network" will be defined as a system wherein the data to be processed is separated into discrete values which are then operated on and combined in at least a two stage process and where the operation performed on the data at each stage is in general different for each discrete value and where the operation performed is at least determined through a training process.

The implementation of neural networks can take on at least two forms, an algorithm programmed on a digital microprocessor, DSP or in a neural computer. In this regard, it is noted that neural computer chips are now becoming available.

In the example above, only a single component failure was discussed using only a single sensor since the data from the single sensor contains a pattern which the neural network was trained to recognize as either normal operation of the component or abnormal operation of the component. The diagnostic module 170 contains preprocessing and neural

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network algorithms for a number of component failures. The neural network algorithms are generally relatively simple, requiring only a few lines of computer code. A single general neural network program can be used for multiple pattern recognition cases by specifying different coefficients for the various terms, one set for each application. Thus, adding different diagnostic checks has only a small affect on the cost of the system. Also, the system has available to it all of the information available on the data bus. During the training process, the pattern recognition program sorts out from the available vehicle data on the data bus or from other sources, those patterns that predict failure of a particular component.

In FIG. 3, a schematic of a vehicle with several components and several sensors is shown in their approximate locations on a vehicle along with a total vehicle diagnostic system in accordance with the invention utilizing a diagnostic module in accordance with the invention. A flow diagram of information passing from the various sensors shown on FIG. 3 onto the vehicle data bus and thereby into the diagnostic device in accordance with the invention is shown in FIG. 4 along with outputs to a display for notifying the driver and to the vehicle cellular phone, or other communication device, for notifying the dealer, vehicle manufacturer or other entity concerned with the failure of a component in the vehicle. If the vehicle is operating on a smart highway, for example, the pending component failure information may also be communicated to a highway control system and/or to other vehicles in the vicinity so that an orderly exiting of the vehicle from the smart highway can be facilitated. FIG. 4 also contains the names of the sensors shown numbered on FIG. 3.

Sensor 1 is a crash sensor having an accelerometer (alternately one or more dedicated accelerometers can be used), sensor 2 is represents one or more microphones, sensor 3 is a coolant thermometer, sensor 4 is an oil pressure sensor, sensor 5 is an oil level sensor, sensor 6 is an air flow meter, sensor 7 is a voltmeter, sensor 8 is an ammeter, sensor 9 is a humidity sensor, sensor 10 is an engine knock sensor, sensor 11 is an oil turbidity sensor, sensor 12 is a throttle position sensor, sensor 13 is a steering torque sensor, sensor 14 is a wheel speed sensor, sensor 15 is a tachometer, sensor 16 is a speedometer, sensor 17 is an oxygen sensor, sensor 18 is a pitch/roll sensor, sensor 19 is a clock, sensor 20 is an odometer, sensor 21 is a power steering pressure sensor, sensor 22 is a pollution sensor, sensor 23 is a fuel gauge, sensor 24 is a cabin thermometer, sensor 25 is a transmission fluid level sensor, sensor 26 is a yaw sensor, sensor 27 is a coolant level sensor, sensor 28 is a transmission fluid turbidity sensor, sensor 29 is brake pressure sensor and sensor 30 is a coolant pressure sensor. Other possible sensors include a temperature transducer, a pressure transducer, a liquid level sensor, a flow meter, a position sensor, a velocity sensor, a RPM sensor, a chemical sensor and an angle sensor, angular rate sensor or Horoscope.

If a distributed group of acceleration sensors or accelerometers are used to permit a determination of the location of a vibration source, the same group can, in some cases, also be used to measure the pitch, yaw and/or roll of the vehicle eliminating the need for dedicated angular rate sensors: In addition, as mentioned above, such a suite of sensors can also be used to determine the location and severity of a vehicle crash and additionally to determine that the vehicle is on the verge of rolling over. Thus, the same suite of accelerometers optimally performs a variety of functions including inertial navigation, crash sensing, vehicle diagnostics, roll over sensing etc.

Consider now some examples. The following is a partial list of potential component failures and the sensors from the



list on FIG. 4 that might provide information to predict the failure of the component:

Out of balance tires	1, 13, 14, 15, 20, 21
Front end out of alignment	1, 13, 21, 26
Tune up required	1, 3, 10, 12, 15, 17, 20, 22
Oil change needed	3, 4, 5, 11
Motor failure	1, 2, 3, 4, 5, 6, 10, 12, 15, 17, 22
Low tire pressure	1, 13, 14, 15, 20, 21
Front end looseness	1, 13, 16, 21, 26
Cooling system failure	3, 15, 24, 27, 30
Alternator problems	1, 2, 7, 8, 15, 19, 20
Transmission problems	1, 3, 12, 15, 16, 20, 25, 28
Differential problems	1, 12, 14
Brakes	1, 2, 14, 18, 20, 26, 29
Catalytic converter and muffler	1, 2, 12, 15, 22
Ignition	1, 2, 7, 8, 9, 10, 12, 17, 23
Tire wear	1, 13, 14, 15, 18, 20, 21, 26
Fuel leakage	20, 23
Fan belt slippage	1, 2, 3, 7, 8, 12, 15, 19, 20
Alternator deterioration	1, 2, 7, 8, 15, 19
Coolant pump failure	1, 2, 3, 24, 27, 30
Coolant hose failure	1, 2, 3, 27, 30
Starter failure	1, 2, 7, 8, 9, 12, 15
Dirty air filter	2, 3, 6, 11, 12, 17, 22

Several interesting facts can be deduced from a review of the above list. First, all of the failure modes listed can be at least partially sensed by multiple sensors. In many cases, some of the sensors merely add information to aid in the interpretation of signals received from other sensors. In today's automobile, there are few if any cases where multiple sensors are used to diagnose or predict a problem. In fact, there is virtually no failure prediction undertaken at all. Second, many of the failure modes listed require information from more than one sensor. Third, information for many of the failure modes listed can not be obtained by observing one data point in time as is now done by most vehicle sensors. Usually an analysis of the variation in a parameter as a function of time is necessary. In fact, the association of data with time to create a temporal pattern for use in diagnosing component failures in automobile is unique to this invention as in the combination of several such temporal patterns. Fourth, the vibration measuring capability of the airbag crash sensor, or other accelerometer, is useful for most of the cases discussed above yet there is no such current use of accelerometers. The airbag crash sensor is used only to detect crashes of the vehicle. Fifth, the second most used sensor in the above list, a microphone, does not currently appear on any automobiles yet sound is the signal most often used by vehicle operators and mechanics to diagnose vehicle problems. Another sensor that is listed above which also does not currently appear on automobiles is a pollution sensor. This is typically a chemical sensor mounted in the exhaust system for detecting emissions from the vehicle. It is expected that this and other chemical sensors will be used more in the future.

In addition, from the foregoing depiction of different sensors which receive signals from a plurality of components, it is possible for a single sensor to receive and output signals from a plurality of components which are then analyzed by the processor to determine if any one of the components for which the received signals were obtained by that sensor is operating in an abnormal state. Likewise, it is also possible to provide for a multiplicity of sensors each receiving a different signal related to a specific component which are then analyzed by the processor to determine if that component is operating in an abnormal state. Note that neural networks can simultaneously analyze data from multiple sensors of the same type or different types.

The discussion above has centered on notifying the vehicle operator of a pending problem with a vehicle component. Today, there is great competition in the automobile marketplace and the manufacturers and dealers who are most responsive to customers are likely to benefit by increased sales both from repeat purchasers and new customers. The diagnostic module disclosed herein benefits the dealer by making him instantly aware, through the cellular telephone system, or other communication link, coupled to the diagnostic module or system in accordance with the invention, when a component is likely to fail. As envisioned, on some automobiles, when the diagnostic module 170 detects a potential failure it not only notifies the driver through a display 210, but also automatically notifies the dealer through a vehicle cellular phone 220. The dealer can thus contact the vehicle owner and schedule an appointment to undertake the necessary repair at each party's mutual convenience. The customer is pleased since a potential vehicle breakdown has been avoided and the dealer is pleased since he is likely to perform the repair work. The vehicle manufacturer also benefits by early and accurate statistics on the failure rate of vehicle components. This early warning system can reduce the cost of a potential recall for components having design defects. It could even have saved lives if such a system had been in place during the Firestone tire failure problem mentioned above. The vehicle manufacturer will thus be guided toward producing higher quality vehicles thus improving his competitiveness. Finally, experience with this system will actually lead to a reduction in the number of sensors on the vehicle since only those sensors that are successful in predicting failures will be necessary.

For most cases it is sufficient to notify a driver that a component is about to fail through a warning display. In some critical cases, action beyond warning the driver may be required. If, for example, the diagnostic module detected that the alternator was beginning to fail, in addition to warning the driver of this eventuality, the module could send a signal to another vehicle system to turn off all non-essential devices which use electricity, thereby conserving electrical energy and maximizing the time and distance that the vehicle can travel before exhausting the energy in the batter. Additionally, this system can be coupled to a system such as OnStar or a vehicle route guidance system, and the driver can be guided to the nearest open repair facility or a facility of his or her choice.

In the discussion above, the diagnostic module of this invention assumes that a vehicle data bus exists which is used by all of the relevant sensors on the vehicle. Most vehicles today do not have a data bus although it is widely believed that most vehicles will have one in the near future. Naturally, the relevant signals can be transmitted to the diagnostic module through a variety of coupling means other than through a data bus and this invention is not limited to vehicles having a data bus. For example, the data can be sent wirelessly to the diagnostic module using the Bluetooth specification. In some cases, even the sensors do not have to be wired and can obtain their power via RF from the interrogator as is well known in the RFID (radio frequency identification) field. Alternately an inductive or capacitive power transfer system can be used.

As can be appreciated from the above discussion, the invention described herein brings several new improvements to automobiles including, but not limited to, the use of pattern recognition technologies to diagnose potential vehicle component failures, the use of trainable systems thereby eliminating the need of complex and extensive

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programming, the simultaneous use of multiple sensors to monitor a particular component, the use of a single sensor to monitor the operation of many vehicle components, the monitoring of vehicle components which have no dedicated sensors, and the notification of both the driver and possibly an outside entity of a potential component failure in time so that the failure can be averted and vehicle breakdowns substantially eliminated. Additionally, improvements to the vehicle stability, crash avoidance, crash anticipation and occupant protection are available.

To implement a component diagnostic system for diagnosing the component utilizing a plurality of sensors not directly associated with the component, i.e., independent of the component, a series of tests are conducted. For each test, the signals received from the sensors are input into a pattern recognition training algorithm with an indication of whether the component is operating normally or abnormally (the component being intentionally altered to provide for abnormal operation). The data from the test are used to generate the pattern recognition algorithm, e.g., neural network, so that in use, the data from the sensors is input into the algorithm and the algorithm provides an indication of abnormal or normal operation of the component. Also, to provide a more versatile diagnostic module for use in conjunction with diagnosing abnormal operation of multiple components, tests may be conducted in which each component is operated abnormally while the other components are operating normally, as well as test in which two or more components are operating abnormally. In this manner, the diagnostic module may be able to determine based on one set of signals from the sensors during use that either a single component or multiple components are operating abnormally.

Furthermore, the pattern recognition algorithm may be trained based on pattern within the signals from the sensors. Thus, by means of a single sensor, it would be possible to determine whether one or more components are operating abnormally. To obtain such a pattern recognition algorithm, tests are conducted using a single sensor, such as a microphone, and causing abnormal operation of one or more components, each component operating abnormally while the other components operate normally and multiple components operating abnormally. In this manner, in use, the pattern recognition algorithm may analyze a signal from a single sensor and determine abnormal operation of one or more components. Note that in some cases, simulations can be used to analytically generate the relevant data.

The invention is also particularly useful in light of the foreseeable implementation of smart highways. Smart highways will result in vehicles traveling down highways under partial or complete control of an automatic system, i.e., not being controlled by the driver. The on-board diagnostic system will thus be able to determine failure of a component prior to or upon failure thereof and inform the vehicle's guidance system to cause the vehicle to move out of the stream of traffic, i.e., onto a shoulder of the highway, in a safe and orderly manner. Moreover, the diagnostic system may be controlled or programmed to prevent the movement of the disabled vehicle back into the stream of traffic until the repair of the component is satisfactorily completed.

In a method in accordance with this embodiment, the operation of the component would be monitored and if abnormal operation of the component is detected, e.g., by any of the methods and apparatus disclosed herein (although other component failure systems may of course be used in this implementation), the guidance system of the vehicle, which controls the movement of the vehicle would be

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notified, e.g., via a signal from the diagnostic module to the guidance system, and the guidance system would be programmed to move the vehicle out of the stream of traffic, or off of the restricted roadway, possibly to a service station or dealer, upon reception of the particular signal from the diagnostic module. The automatic guidance systems for vehicles traveling on highways may be any existing system or system being developed, such as one based on satellite positioning techniques or ground-based positioning techniques. Since the guidance system may be programmed to ascertain the vehicle's position on the highway, it can determine the vehicle's current position, the nearest location out of the stream of traffic, or off of the restricted roadway, such as an appropriate shoulder or exit to which the vehicle may be moved, and the path of movement of the vehicle from the current position to the location out of the stream of traffic, or off of the restricted roadway. The vehicle may thus be moved along this path under the control of the automatic guidance system. In the alternative, the path may be displayed to a driver and the driver can follow the path, i.e., manually control the vehicle. The diagnostic module and/or guidance system may be designed to prevent re-entry of the vehicle into the stream of traffic, or off of the restricted roadway, until the abnormal operation of the component is satisfactorily addressed.

FIG. 5 is a flow chart of some of the methods for directing a vehicle off of a roadway if a component is operating abnormally. The component's operation is monitored at 40 and a determination is made at 42 whether its operation is abnormal. If not, the operation of the component is monitored further. If the operation of the component is abnormal, the vehicle can be directed off the roadway at 44. More particularly, this can be accomplished by generating a signal indicating the abnormal operation of the component at 46, directing this signal to a guidance system in the vehicle at 48 that guides movement of the vehicle off of the roadway at 50. Also, if the component is operating abnormally, the current position of the vehicle and the location of a site off of the roadway can be determined at 52, e.g., using satellite-based or ground-based location determining techniques, a path from the current location to the off-roadway location determined at 54 and then the vehicle directed along this path at 56. Periodically, a determination is made at 58 whether the component's abnormality has been satisfactorily addressed and/or corrected and if so, the vehicle can re-enter the roadway and operation of the component begins again. If not, the re-entry of the vehicle onto the roadway is prevented at 60.

FIG. 6 schematically shows the basic components for performing this method, i.e., a component operation monitoring system 62 (such as described above), an optional satellite-based or ground-based positioning system 64 and a vehicle guidance system 66.

FIG. 7 illustrates the placement of a variety of sensors, primarily accelerometers and/or gyroscopes, which can be used to diagnose the state of the vehicle itself. Sensor 201 can measure the acceleration of the firewall or instrument panel and is located thereon generally midway between the two sides of the vehicle. Sensor 202 can be located in the headliner or attached to the vehicle roof above the side door. Typically, there will be two such sensors one on either side of the vehicle. Sensor 203 is shown in a typical mounting location midway between the sides of the vehicle attached to or near the vehicle roof above the rear window. Sensor 206 is shown in a typical mounting location in the vehicle trunk adjacent the rear of the vehicle. Either one, two or three such sensors can be used depending on the application. If three

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such sensors are use one would be adjacent each side of vehicle and one in the center. Sensor **204** is shown in a typical mounting location in the vehicle door and sensor **205** is shown in a typical mounting location on the sill or floor below the door. Finally, sensor **207**, which can be also multiple sensors, is shown in a typical mounting location forward in the crush zone of the vehicle. If three such sensors are used, one would be adjacent each vehicle side and one in the center.

In general, sensors **201–207** provide a measurement of the state of the sensor, such as its velocity, acceleration, angular orientation or temperature, or a state of the location at which the sensor is mounted. Thus, measurements related to the state of the sensor would include measurements of the acceleration of the sensor, measurements of the temperature of the mounting location as well as changes in the state of the sensor and rates of changes of the state of the sensor. As such, any described use or function of the sensors **201–207** above is merely exemplary and is not intended to limit the form of the sensor or its function.

Each of the sensors **201–207** may be single axis, double axis or triaxial accelerometers and/or gyroscopes typically of the MEMS type. These sensors **201–207** can either be wired to the central control module or processor directly wherein they would receive power and transmit information, or they could be connected onto the vehicle bus or, in some cases, using RFID technology, the sensors can be wireless and would receive their power through RF from one or more interrogators located in the vehicle. In this case, the interrogators can be connected either to the vehicle bus or directly to control module. Alternately, an inductive or capacitive power and information transfer system can be used.

One particular implementation will now be described. In this case, each of the sensors **201–207** is a single or dual axis accelerometer. They are made using silicon micromachined technology such as disclosed in U.S. Pat. Nos. 5,121,180 and 5,894,090. These are only representative patents of these devices and there exist more than 100 other relevant U.S. patents describing this technology. Commercially available MEMS gyroscopes such as from Systron Doner have accuracies of approximately one degree per second. In contrast, optical gyroscopes typically have accuracies of approximately one degree per hour. Unfortunately, the optical gyroscopes are prohibitively expensive for automotive applications. On the other hand, typical MEMS gyroscopes are not sufficiently accurate for many control applications.

The angular rate function can be obtained through placing accelerometers at two separated, non-co-located points in a vehicle and using the differential acceleration to obtain an indication of angular motion and angular acceleration. From the variety of accelerometers shown on FIG. 7, it can be readily appreciated that not only will all accelerations of key parts of the vehicle be determined; but the pitch, yaw and roll angular rates can also be determined based on the accuracy of the accelerometers. By this method, low cost systems can be developed which, although not as accurate as the optical gyroscopes, are considerably more accurate than conventional MEMS gyroscopes.

Instead of using two accelerometers are separate locations on the vehicle, a single conformal MEMS-IDT gyroscope may be used. Such a conformal MEMS-IDT gyroscope is describes in a paper by V. K. Karadan, Conformal MEMS-IDT Gyroscopes and Their-Comparison With Fiber Optic Gyro, incorporated in its entirety herein. The MEMS-IDT gyroscope is based on the principle of surface acoustic wave (SAW) standing waves on a piezoelectric substrate. A sur-

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face acoustic wave resonator is used to create standing waves inside a cavity and the particles at the anti-nodes of the standing waves experience large amplitude of vibrations, which serves as the reference vibrating motion for the gyroscope. Arrays of metallic dots are positioned at the anti-node locations so that the effect of Coriolis force due to rotation will acoustically amplify the magnitude of the waves. Unlike other MEMS gyroscopes, the MEMS-IDT gyroscope has a planar configuration with no suspended resonating mechanical structures.

The system of FIG. 7 using dual axis accelerometers, therefore provide a complete diagnostic system of the vehicle itself and its dynamic motion. Such a system is far more accurate than any system currently available in the automotive market. This system provides very accurate crash discrimination since the exact location of the crash can be determined and, coupled with a knowledge of the force deflection characteristics of the vehicle at the accident impact site, an accurate determination of the crash severity and thus the need for occupant restraint deployment can be made. Similarly, the tendency of a vehicle to roll over can be predicted in advance and signals sent to the vehicle steering, braking and throttle systems to attempt to ameliorate the rollover situation or prevent it. In the event that it cannot be prevented, the deployment side curtain airbags can be initiated in a timely manner.

Similarly, the tendency of the vehicle to the slide or skid can be considerably more accurately determined and again the steering, braking and throttle systems commanded to minimize the unstable vehicle behavior.

Thus, through the sample deployment of inexpensive accelerometers at a variety of locations in the vehicle, significant improvements are many in the vehicle stability control, crash sensing, rollover sensing, and resulting occupant protection technologies.

Finally, as mentioned above, the combination of the outputs from these accelerometer sensors and the output of strain gage weight sensors in a vehicle seat, or in or on a support structure of the seat, can be used to make an accurate assessment of the occupancy of the seat and differentiate between animate and inanimate occupants as well as determining where in the seat the occupants are sitting. This can be done by observing the acceleration signals from the sensors of FIG. 7 and simultaneously the dynamic strain gage measurements from seat mounted strain gages. The accelerometers provide the input function to the seat and the strain gages measure the reaction of the occupying item to the vehicle acceleration and thereby provide a method of determining dynamically the mass of the occupying item and its location. This is particularly important during occupant position sensing during a crash event. By combining the outputs of the accelerometers and the strain gages and appropriately processing the same, the mass and weight of an object occupying the seat can be determined as well as the gross motion of such an object so that an assessment can be made as to whether the object is a life form such as a human being.

For this embodiment, sensor **208** represents one or more strain gage weight sensors mounted on the seat or in connection with the seat or its support structure. Suitable mounting locations and forms of weight sensors are discussed in the current assignee's U.S. patent application Ser. No. 09/193,209 and contemplated for use in this invention as well. The mass or weight of the occupying item of the seat can thus be measured based on the dynamic measurement of the strain gages with optional consideration of the measurements of accelerometers on the vehicle, which are represented by any of sensors **201–207**.



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Thus, discussed above is an embodiment of a component diagnostic system for diagnosing the component in accordance with the invention which comprises a plurality of sensors not directly associated with the component, i.e., independent therefrom, such that the component does not directly affect the sensors, each sensor detecting a signal containing information as to whether the component is operating normally or abnormally and outputting a corresponding electrical signal, processor means coupled to the sensors for receiving and processing the electrical signals and for determining if the component is operating abnormally based on the electrical signals, and output means coupled to the processor means for affecting another system within the vehicle if the component is operating abnormally. The processor means preferably comprise pattern recognition means such as a trained pattern recognition algorithm, a neural network, modular neural networks or an ensemble of neural networks. In some cases, fuzzy logic will be used which can be combined with a neural network to form a neural fuzzy algorithm. The another system may be a display for indicating the abnormal state of operation of the component arranged in a position in the vehicle to enable a driver of the vehicle to view the display and thus the indicated abnormal operation of the component. At least one source of additional information, e.g., the time and date, may be provided and input means coupled to the vehicle for inputting the additional information into the processor means. The another system may also be a warning device including transmission means for transmitting information related to the component abnormal operating state to a site remote from the vehicle, e.g., a vehicle repair facility.

In another embodiment of the component diagnostic system discussed above, at least one sensor detects a signal containing information as to whether the component is operating normally or abnormally and outputs a corresponding electrical signal. Processor means are coupled to the sensor(s) for receiving and processing the electrical signal(s) and for determining if the component is operating abnormally based thereon. The processor means preferably comprise a pattern recognition algorithm for analyzing a pattern within the signal detected by each sensor. Output means are coupled to the processor means for affecting another system within the vehicle if the component is operating abnormally. The another system may be a display as mentioned above or a warning device.

A method for automatically monitoring one or more components of a vehicle during operation of the vehicle on a roadway entails, as discussed above, the steps of monitoring operation of the component in order to detect abnormal operation of the component, e.g., in one or the ways described above, and if abnormal operation of the component is detected, automatically directing the vehicle off of the restricted roadway. For example, in order to automatically direct the vehicle off of the restricted roadway, a signal representative of the abnormal operation of the component may be generated and directed to a guidance system of the vehicle that guides the movement of the vehicle. Possibly the directing the vehicle off of the restricted roadway may entail applying satellite positioning techniques or ground-based positioning techniques to enable the current position of the vehicle to be determined and a location off of the restricted highway to be determined and thus a path for the movement of the vehicle. Re-entry of the vehicle onto the restricted roadway may be prevented until the abnormal operation of the component is satisfactorily addressed.

Although several preferred embodiments are illustrated and described above, there are possible combinations using

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other signals and sensors for the components and different forms of the neural network implementation or different pattern recognition technologies that perform the same functions which can be utilized in accordance with the invention. Also, although the neural network and modular neural networks have been described as an example of one means of pattern recognition, other pattern recognition means exist and still others are being developed which can be used to identify potential component failures by comparing the operation of a component over time with patterns characteristic of normal and abnormal component operation. In addition, with the pattern recognition system described above, the input data to the system may be data which has been pre-processed rather than the raw signal data either through a process called "feature extraction" or by various mathematical transformations. Also, any of the apparatus and methods disclosed herein may be used for diagnosing the state of operation or a plurality of discrete components. This invention is not limited to the above embodiments and should be determined by the following claims.

What is claimed is:

1. In a motor vehicle, a control system for controlling at least one part of the vehicle comprising:

a plurality of sensor systems mounted at different locations on the vehicle, each of said sensor systems providing a measurement related to a state of said sensor system or a measurement related to a state of the mounting location; and

a processor coupled to said sensor systems and arranged to diagnose the state of the vehicle based on the measurements of said sensor systems,

said processor being arranged to control the at least one part based at least in part on the diagnosed state of the vehicle.

2. The vehicle of claim 1, wherein at least one of said sensor systems is a sensor selected from a group consisting of a single axis acceleration sensor, a double axis acceleration sensor, a triaxial acceleration sensor and a gyroscope.

3. The vehicle of claim 1, wherein at least one of said sensor systems includes an RFID response unit, further comprising at least one RFID interrogator device, said at least one interrogator device causing said RFID response units of said at least one sensor system to transmit a signal representative of the measurement of said at least one sensor system to said processor.

4. The vehicle of claim 1, wherein the state of the vehicle diagnosed by said processor includes angular motion of the vehicle.

5. The vehicle of claim 4, wherein the at least one part is a system selected from a group consisting of a steering system, a braking system or a throttle system, said processor being arranged to control the system in an attempt to maintain stability of the vehicle.

6. The vehicle of claim 5, wherein the at least one part is an occupant restraint device, said processor being arranged to control the occupant restraint device in an attempt to minimize injury to an occupant.

7. The vehicle of claim 1, wherein the state of the vehicle diagnosed by said processor includes a determination of a location of an impact between the vehicle and another object.

8. The vehicle of claim 7, wherein the at least one part is an occupant restraint device, said processor being arranged to forecast the severity of the impact using the force/crush properties of the vehicle at the impact location and control the occupant restraint device based at least in part on the severity of the impact.

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9. The vehicle of claim 1, wherein the at least one part is an occupant restraint device.

10. The vehicle of claim 9, further comprising a weight sensing system coupled to a seat in the vehicle for sensing the weight of an occupying item of the seat, said weight sensing system being coupled to said processor and said processor controlling the occupant restraint device based on the state of the vehicle and the weight of the occupying item of the seat sensed by said weight sensing system.

11. The vehicle of claim 1, wherein said processor includes pattern recognition means for diagnosing the state of the vehicle.

12. The vehicle of claim 1, further comprising a display coupled to said processor for displaying an indication of the state of the vehicle as diagnosed by said processor.

13. The vehicle of claim 1, further comprising a warning device coupled to said processor for relaying a warning to an occupant of the vehicle relating to the state of the vehicle as diagnosed by said processor.

14. The vehicle of claim 1, further comprising a transmission device coupled to said processor for transmitting a signal to a remote site relating to the state of the vehicle as diagnosed by said processor.

15. The vehicle of claim 1, wherein the state of the vehicle includes angular acceleration, a plurality of said sensor systems comprising accelerometers such that said processor determines the angular acceleration of the vehicle based on the acceleration measured by said accelerometers.

16. The vehicle of claim 1, wherein at least one of said sensor systems comprises a high dynamic range accelerometer.

17. The vehicle of claim 1, wherein at least one of said sensors comprises a gyroscope including a surface acoustic wave resonator which applies standing waves on a piezoelectric substrate.

18. The vehicle of claim 1, wherein the state of the vehicle diagnosed by said processor includes angular acceleration of the vehicle whereby angular velocity and angular position or orientation are derivable from the angular acceleration the at least one part being a navigation system, said processor being arranged to control said navigation system based on the angular acceleration of the vehicle.

19. A method for controlling at least one part of the vehicle comprising the steps of mounting a plurality of sensor systems at different locations on the vehicle;

measuring a state of the sensor system or a state of the respective mounting location of the sensor system; diagnosing the state of the vehicle based on the measurements of the state of the sensor systems or the state of the mounting locations of the sensor systems, and controlling the at least one part based at least in part on the diagnosed state of the vehicle.

20. The method of claim 19, wherein the state of the sensor system is the acceleration, angular acceleration, angular velocity or angular orientation of the sensor system.

21. The method of claim 19, wherein the state of the vehicle is diagnosed by a processor, further comprising the steps of:

providing at least one of the sensor systems with an RFID response unit;

mounting at least one RFID interrogator device on the vehicle; and

transmitting signals via the at least one RFID interrogator device to cause the RFID response units of the at least one sensor system to transmit a signal representative of the measurements of the at least one sensor system to the processor.

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22. The method of claim 19, wherein the step of diagnosing the state of the vehicle comprises the step of determining whether the vehicle is stable or is about to rollover or skid.

23. The method of claim 19, wherein the at least one part is a system selected from a group consisting of a steering system, a braking system or a throttle system, the step of controlling the at least one part comprising the step of controlling the system in an attempt to maintain stability of the vehicle.

24. The method of claim 19, wherein the at least one part is an occupant restraint device, the step of controlling the at least one part comprising the steps of controlling the system in an attempt to minimize injury to an occupant in the event of a crash.

25. The method of claim 19, wherein the step of diagnosing the state of the vehicle comprises the step of determining a location of an impact between the vehicle and another object.

26. The method of claim 25, wherein the at least one part is an occupant restraint device, further comprising the step of forecasting the severity of the impact using the force/crush properties of the vehicle at the impact location, the step of controlling the at least one part comprising the step of controlling the occupant restraint device based at least in part on the severity of the impact.

27. The method of claim 19, wherein the at least one part is an occupant restraint device, further comprising the step of sensing the weight of an occupying item of a seat of the vehicle, the step of controlling the at least one part comprising the step of controlling the occupant restraint device based at least in part on the weight of the occupying item of the seat.

28. The method of claim 19, further comprising the step of displaying an indication of the state of the vehicle.

29. The method of claim 19, further comprising the step of relaying a warning to an occupant of the vehicle relating to the state of the vehicle.

30. The method of claim 19, further comprising the step of transmitting a signal to a remote site relating to the state of the vehicle.

31. The method of claim 19, wherein a plurality of the sensor systems comprises accelerometers, the step of diagnosing the state of the vehicle comprises the step of determining angular acceleration of the vehicle based on the acceleration measured by said accelerometers.

32. The method of claim 19, wherein the step of diagnosing the state of the vehicle comprises the step of determining angular acceleration of the vehicle whereby angular velocity and angular position or orientation are derivable from the angular acceleration, the at least one part being a navigation system, the step of controlling the at least one part comprising the controlling the navigation system based on the angular acceleration of the vehicle.

33. In a motor vehicle, a control system for controlling at least one part of the vehicle comprising:

a plurality of sensor systems mounted on the vehicle, each of said sensor systems providing a measurement of a state of said sensor system or a state of the mounting location of said sensor system and generating a signal representative of the measurement; and

a pattern recognition system for receiving the signals from said sensor systems and diagnosing the state of the vehicle based on the measurements of said sensor systems,

said pattern recognition system being arranged to generate a control signal for controlling the at least one part based at least in part on the diagnosed state of the vehicle.



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34. The vehicle of claim 33, wherein said pattern recognition system comprises at least one neural network.

35. The vehicle of claim 33, wherein at least one of said sensor systems is a sensor selected from a group consisting of a single axis acceleration sensor, a double axis acceleration sensor, a triaxial acceleration sensor and a gyroscope.

36. The vehicle of claim 33, wherein the state of the vehicle diagnosed by said processor includes angular orientation, velocity or acceleration of the vehicle.

37. The vehicle of claim 33, wherein the at least one part is a system selected from a group consisting of a steering system, a braking system or a throttle system, said processor being arranged to control the system in an attempt to maintain stability of the vehicle.

38. The vehicle of claim 33, wherein the at least one part is an occupant restraint device, said processor being arranged to control the occupant restraint device in an attempt to minimize injury to an occupant.

39. The vehicle of claim 33, wherein the state of the vehicle diagnosed by said pattern recognition system includes a determination of a location on the vehicle of an impact between the vehicle and another object.

40. The vehicle of claim 39, wherein the at least one part is an occupant restraint device, said pattern recognition system being arranged to forecast the severity of the impact using the force/crush properties of the vehicle at the impact location and generate the control signal for controlling the occupant restraint device based at least in part on the severity of the impact.

41. The vehicle of claim 33, wherein the at least one part is an occupant restraint device, further comprising a weight sensing system coupled to a seat in the vehicle for sensing the weight of an occupying item of the seat, said pattern recognition system generating the control signal for controlling the occupant restraint device based on the state of the vehicle and the weight of the occupying item of the seat sensed by said weight sensing system.

42. The vehicle of claim 33, further comprising a warning device for relaying a warning to an occupant of the vehicle relating to the state of the vehicle as diagnosed by said pattern recognition system.

43. The vehicle of claim 33, further comprising a transmission device for transmitting a signal to a remote site relating to the state of the vehicle as diagnosed by said pattern recognition system.

44. The vehicle of claim 33, wherein the state of the vehicle diagnosed by said pattern recognition system includes a state of an abnormally operating component, said pattern recognition system being arranged to identify a potentially malfunctioning component based on the state of the component measured by said sensor systems and determine whether the identified component is operating abnormally based on the state of the component measured by said sensor systems.

45. The vehicle of claim 33, wherein said pattern recognition system comprises a neural network system and the state of the vehicle diagnosed by said neural network system includes a state of an abnormally operating component, said neural network system including a first neural network arranged to identify a potentially malfunctioning component based on the state of the component measured by said sensor systems and a second neural network for determining whether the identified component is operating abnormally based on the state of the component measured by said sensor systems.

46. The method of claim 33, wherein said pattern recognition system comprises a neural network system and the

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state of the vehicle diagnosed by said neural network system includes a state of an abnormally operating component, said neural network system including a first neural network arranged to identify a potentially malfunctioning component based on the state of the component measured by said sensor systems and a plurality of additional neural networks, each being trained to determine whether a specific component is operating abnormally, whereby the measurements of the state of the component from said sensor systems are input into that one of the additional neural networks trained on a component which is substantially identical to the identified component.

47. The vehicle of claim 33, wherein said sensor systems are mounted at different locations on the vehicle.

48. A method for controlling at least one part of the vehicle, comprising the steps of:

mounting a plurality of sensor systems on the vehicle;  
measuring a state of the sensor system or a state of the respective mounting location of the sensor system;  
generating signals representative of the measurements of the sensor systems;  
inputting the signals into a pattern recognition system to obtain a diagnosis of the state of the vehicle; and  
controlling the at least one part based at least in part on the diagnosis of the state of the vehicle.

49. The method of claim 48, wherein the pattern recognition system comprises at least one neural network.

50. The method of claim 48, wherein the diagnosis of the state of the vehicle includes the angular orientation, angular velocity or angular acceleration of the vehicle.

51. The method of claim 48, wherein the at least one part is a system selected from a group consisting of a steering system, a braking system or a throttle system, the step of controlling the at least one part comprising the step of controlling the system in an attempt to maintain stability of the vehicle.

52. The method of claim 48, wherein the at least one part is an occupant restraint device, the step of controlling the at least one part comprising the steps of controlling the system in an attempt to minimize injury to an occupant in the event of a crash.

53. The method of claim 48, wherein the diagnosis of the state of the vehicle includes a determination of a location on the vehicle of an impact between the vehicle and another object.

54. The method of claim 53, wherein the at least one part is an occupant restraint device, further comprising the step of forecasting the severity of the impact using the force/crush properties of the vehicle at the impact location and generating control signals by the pattern recognition system for controlling the occupant restraint device based at least in part on the severity of the impact.

55. The method of claim 48, wherein the at least one part is an occupant restraint device, further comprising the steps of:

sensing the weight of an occupying item of a seat of the vehicle; and  
generating control signals by the pattern recognition system for controlling the occupant restraint device based on the diagnosis of the state of the vehicle and the weight of the occupying item of the seat.

56. The method of claim 48, further comprising the steps of:

identifying by means of the pattern recognition system a potentially malfunctioning component based on the states measured by the sensor systems; and

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determining by means of the pattern recognition system whether the identified component is operating abnormally based on the states measured by the sensor systems.

57. The method of claim 56, wherein the pattern recognition system comprises a neural network system, the step of identifying the potentially malfunctioning component comprises the step of inputting the states measured by the sensor systems into a first neural network of the neural network system and the step of determining whether the identified component is operating abnormally comprises the step of inputting the states measured by the sensor systems into a second neural network of the neural network system.

58. The method of claim 56, wherein the pattern recognition system comprises a neural network system, the step of identifying the potentially malfunctioning component comprises the step of inputting the states measured by the sensor systems into a first neural network of the neural network system and the step of determining whether the identified component is operating abnormally comprises the steps of providing a plurality of additional neural networks of the neural network system, each being trained to determine whether a specific component is operating abnormally, and inputting the states measured by the sensor systems into that one of the additional neural networks trained on a component which is substantially identical to the identified component.

59. The method of claim 48, further comprising the step of mounting the sensors at different locations on the vehicle.

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60. In a motor vehicle having a seat, a control system for controlling at least one part of the vehicle based on occupancy of the seat, comprising:

a plurality of strain gages mounted in connection with the seat, each of said strain gages measuring strain of a respective mounting location caused by occupancy of the seat, and

a processor coupled to said strain gages and arranged to determine the weight of an occupying item based on the strain measurements from said strain gages over a period of time,

said processor being arranged to control the at least one part based at least in part on the determined weight of the occupying item of the seat.

61. The vehicle of claim 60, wherein said processor is arranged to determine motion of the occupying item of the seat based on the strain measurements from said strain gages over the period of time.

62. The vehicle of claim 60, further comprising at least one accelerometer mounted on the vehicle for measuring acceleration, said processor being arranged to control the at least one part based at least in part on the determined weight of the occupying item of the seat and the acceleration measured by said at least one accelerometer.

\* \* \* \* \*

# **EXHIBIT D**

(10) **Patent No.:**       **US 6,757,602 B2**  
(45) **Date of Patent:**       **Jun. 29, 2004**

- (58) **Field of Search** ..... 701/45, 46, 47;  
180/268, 271, 272, 273; 280/735

- (56) **References Cited**

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| 6,445,988 | B1 * | 9/2002  | Breed et al. ....   | 701/45  |

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*Primary Examiner*—Gertrude A. Jeanglaude

(74) *Attorney, Agent, or Firm*—Brian Roffe

(57) **ABSTRACT**

Method for controlling an occupant protection device in a vehicle in which data is acquired from at least one sensor relating to an occupant in a seat to be protected by the occupant protection device, the type of occupant is classified based on the acquired data and when the occupant is classified as an empty seat or a rear-facing child seat, deployment of the occupant protection device is disabled or adjusted. Otherwise, the size of the occupant is classified based on the acquired data, the position of the occupant is determined by one of a plurality of algorithms selected based on the classified size of the occupant using the acquired data, each algorithm being applicable for a specific size of occupant. Deployment of the occupant protection device is disabled or adjusted when the determined position of the occupant is more likely to result in injury to the occupant if the occupant protection device were to deploy. The algorithms may be pattern recognition algorithms such as neural networks.

- (21) Appl. No.: 10/234,436

- (22) Filed: **Sep. 3, 2002**

(65) **Prior Publication Data**

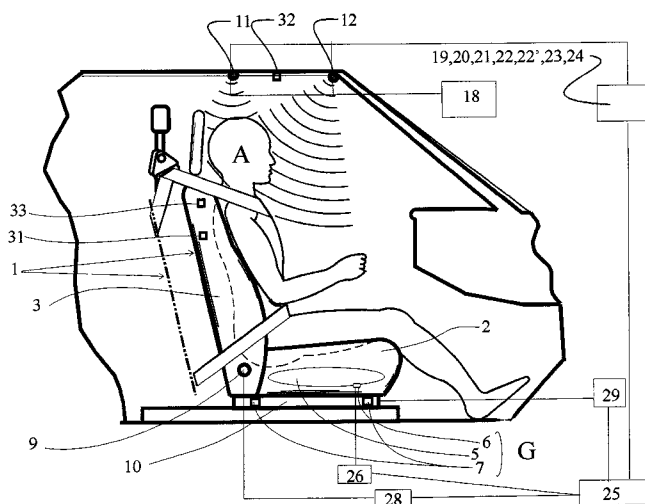
US 2003/0036835 A1 Feb. 20, 2003

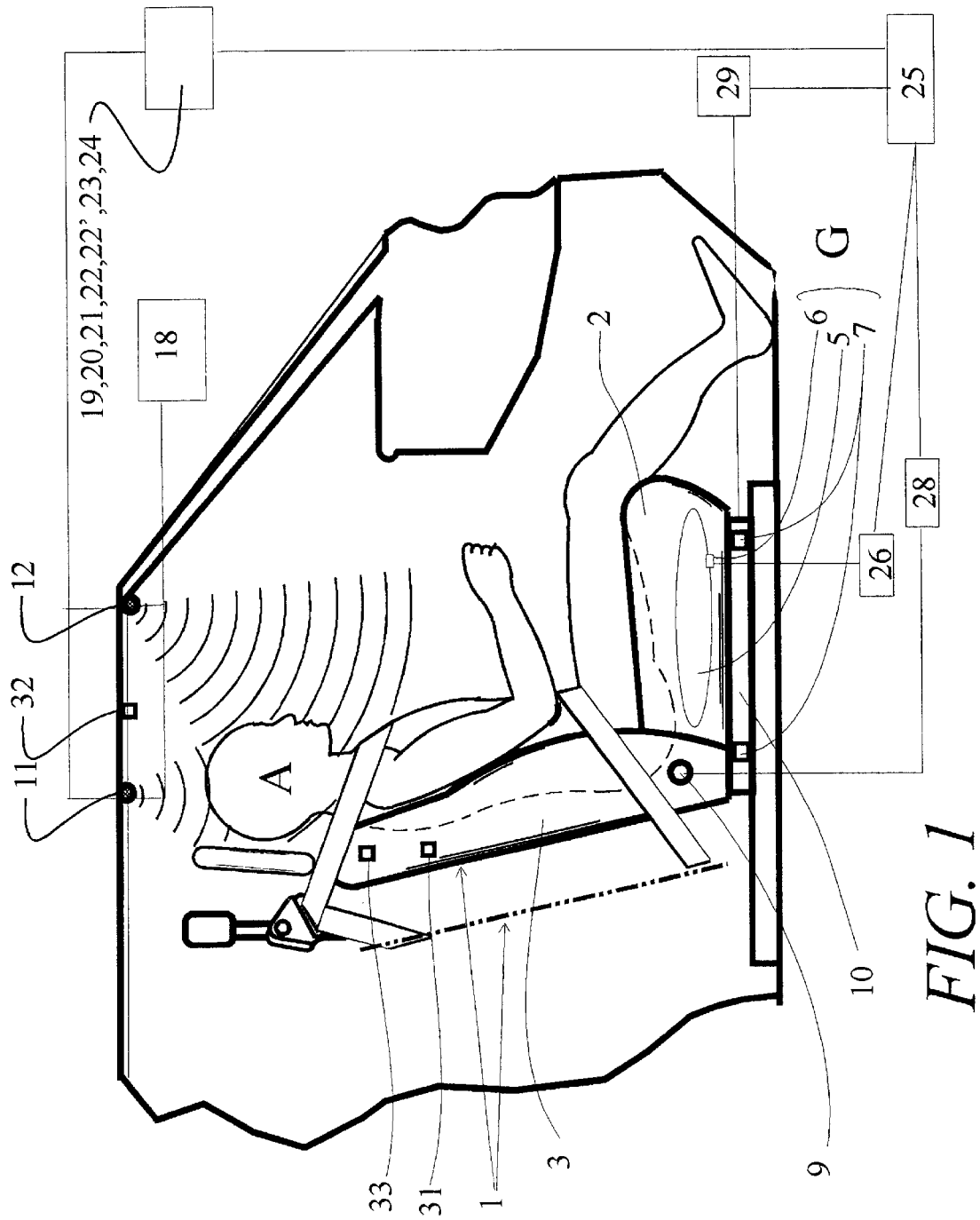
### Related U.S. Application Data

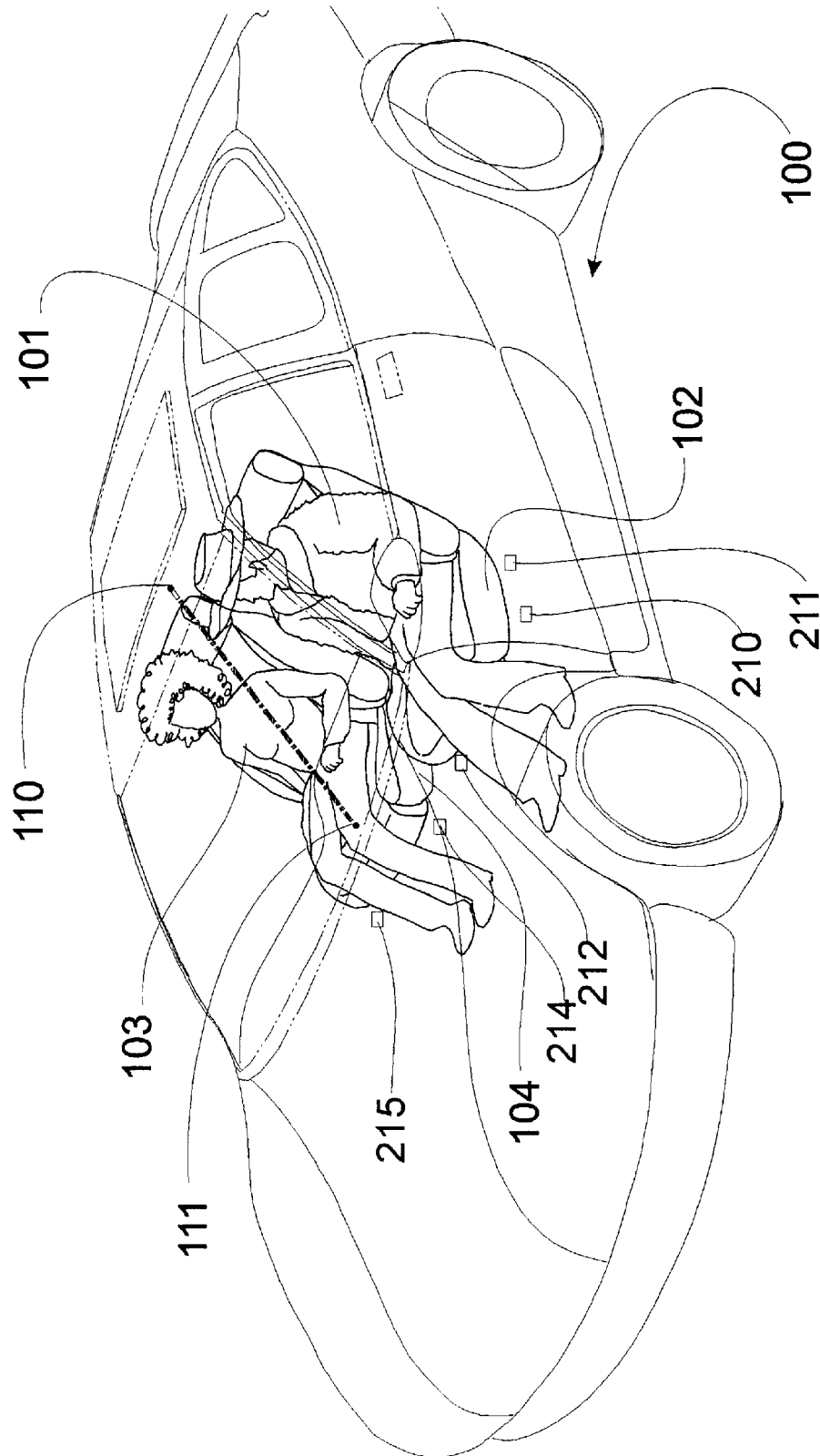
- (63) Continuation-in-part of application No. 09/853,118, filed on May 10, 2001, now Pat. No. 6,445,988, which is a continuation-in-part of application No. 09/382,406, filed on Aug. 24, 1999, now Pat. No. 6,529,809, which is a continuation-in-part of application No. 09/474,147, filed on Dec. 29, 1999, now Pat. No. 6,397,136, which is a continuation-in-part of application No. 08/798,029, filed on Feb. 6, 1997, now abandoned, which is a continuation-in-part of application No. 08/919,823, filed on Aug. 28, 1997, now Pat. No. 5,943,295.
- (60) Provisional application No. 60/136,163, filed on May 27, 1999.

- (51) **Int. Cl.**<sup>7</sup> ..... **G06F 7/00**

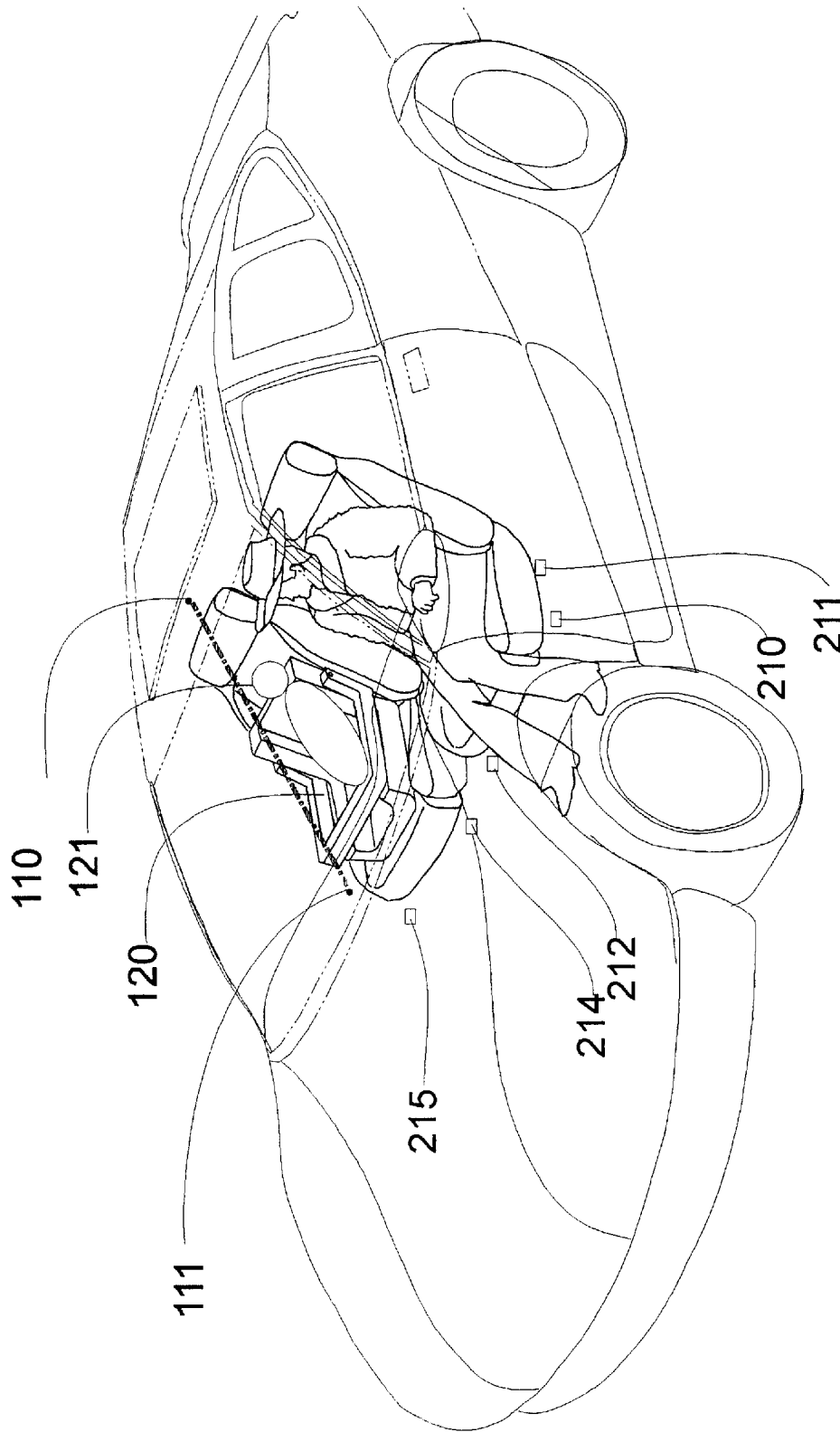
## 56 Claims, 50 Drawing Sheets







**FIG. 2**



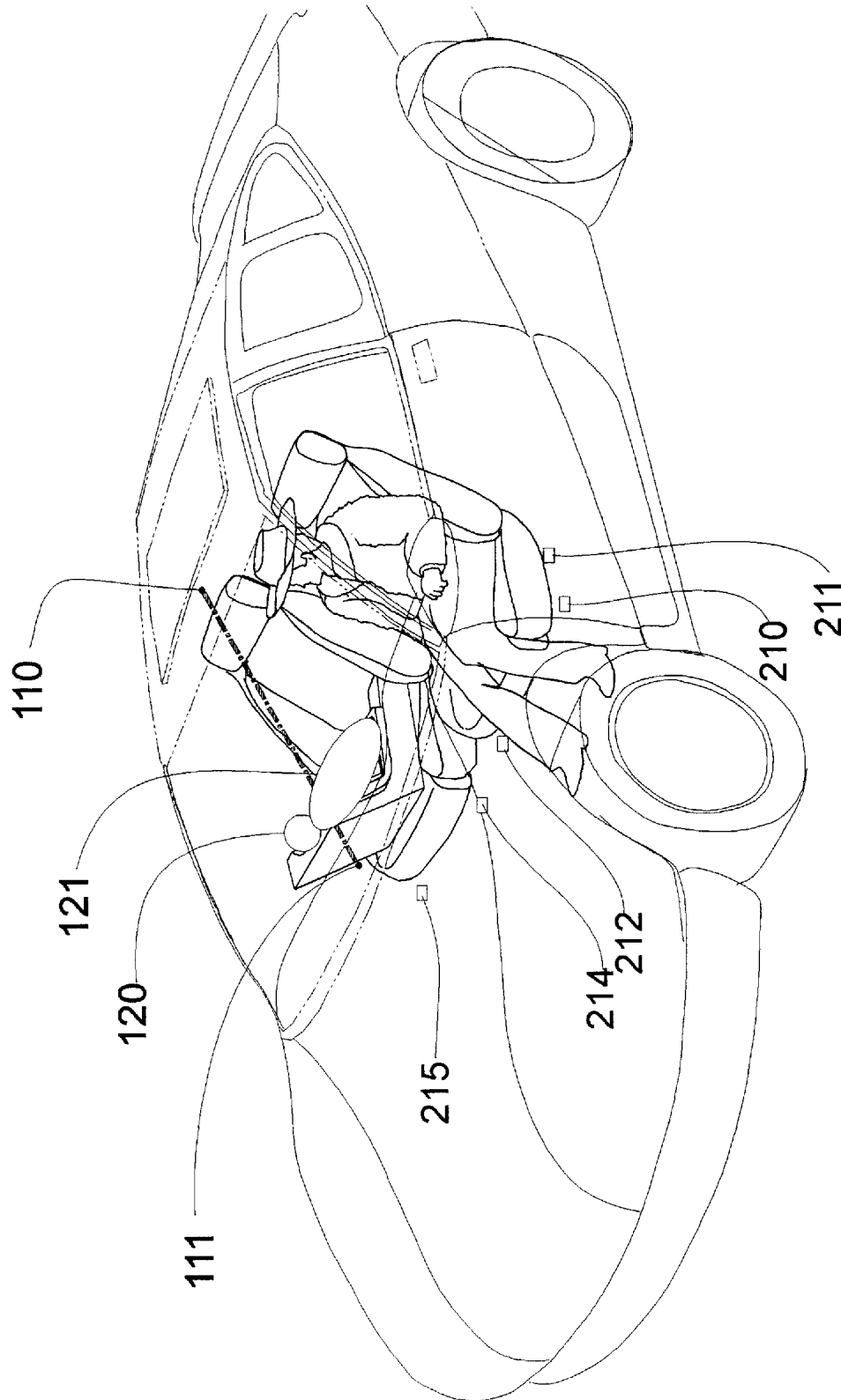
**FIG. 3**

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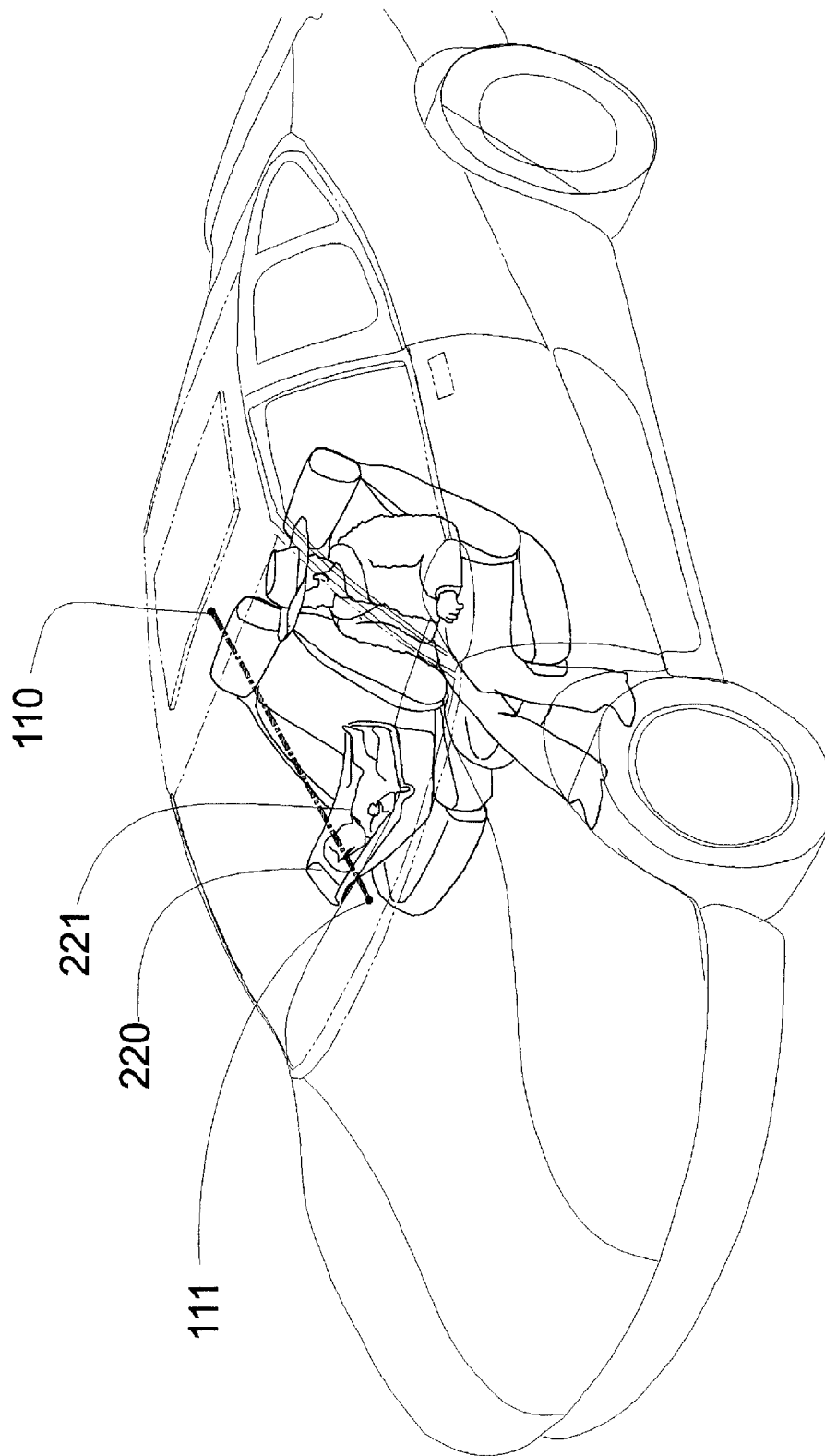
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**FIG. 4**





**FIG. 5**

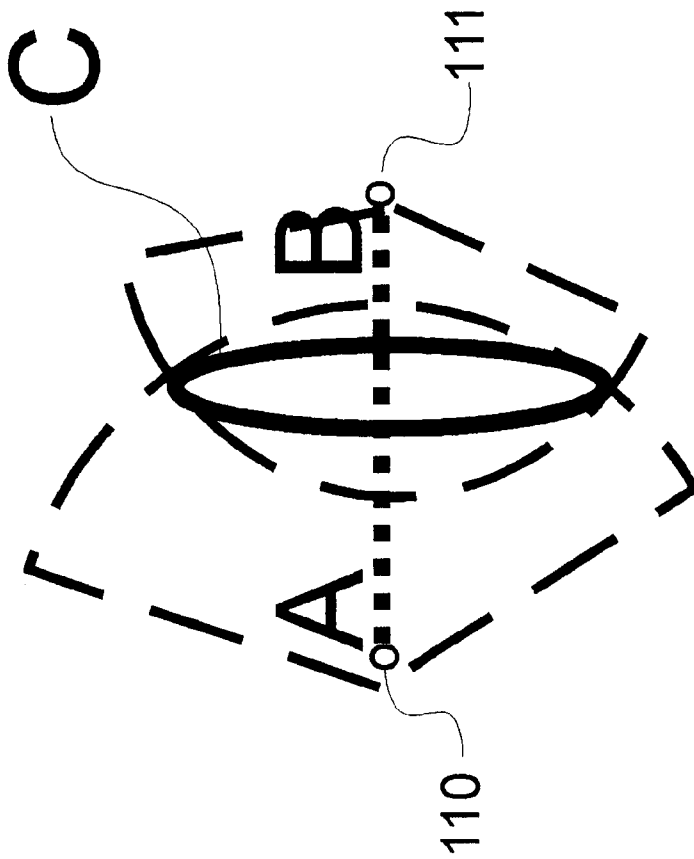
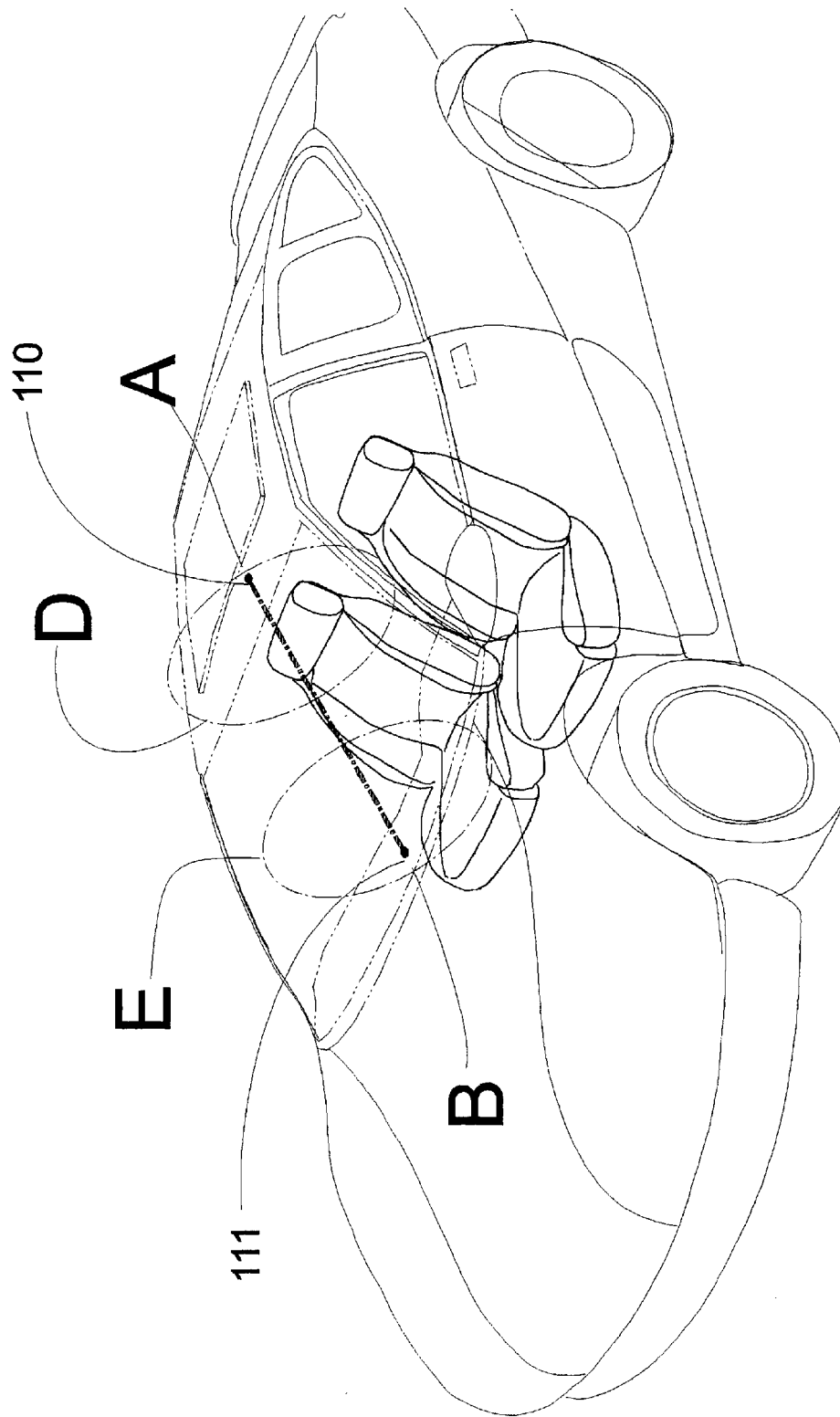


FIG. 6



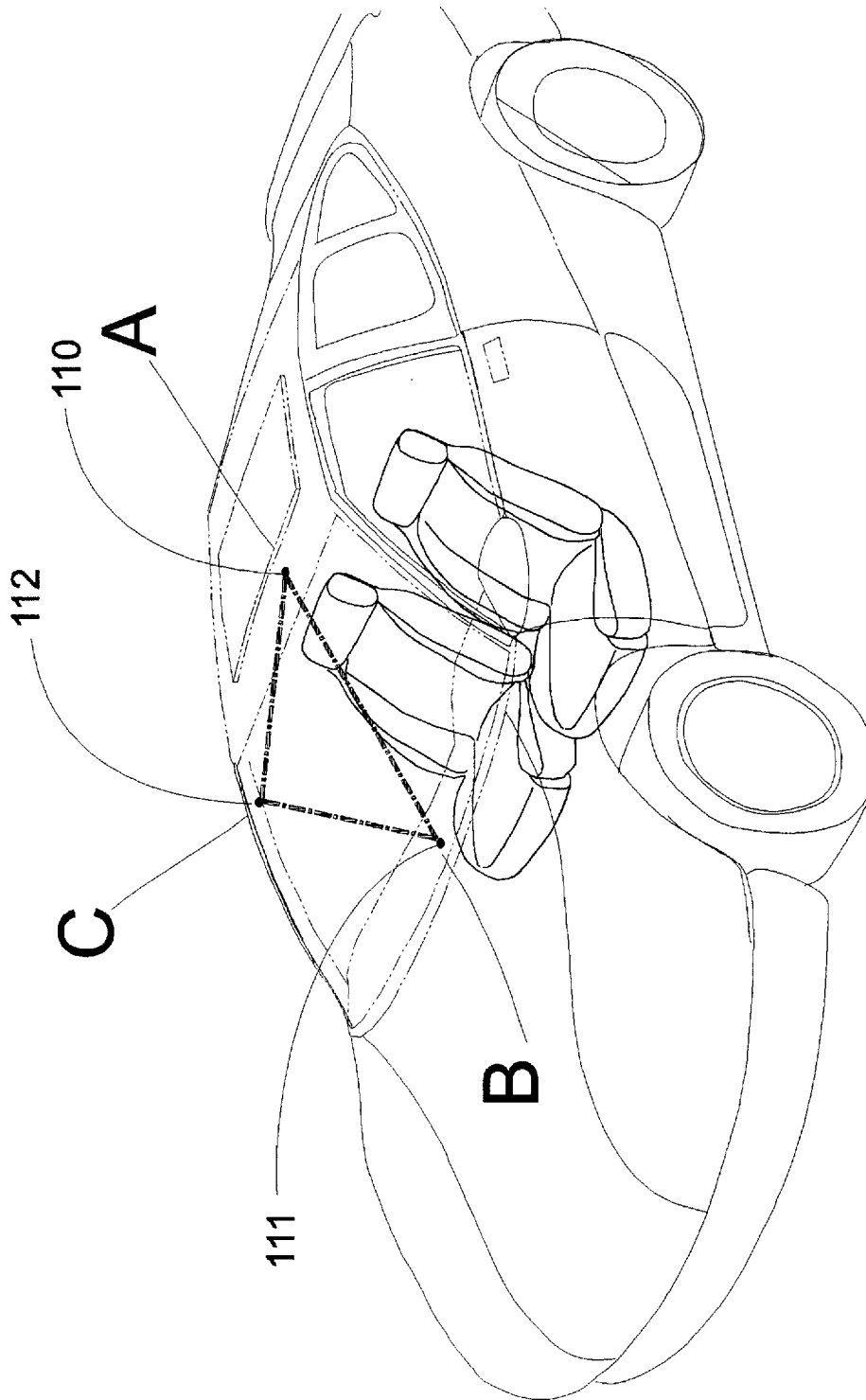
**FIG. 7**

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**FIG. 8**

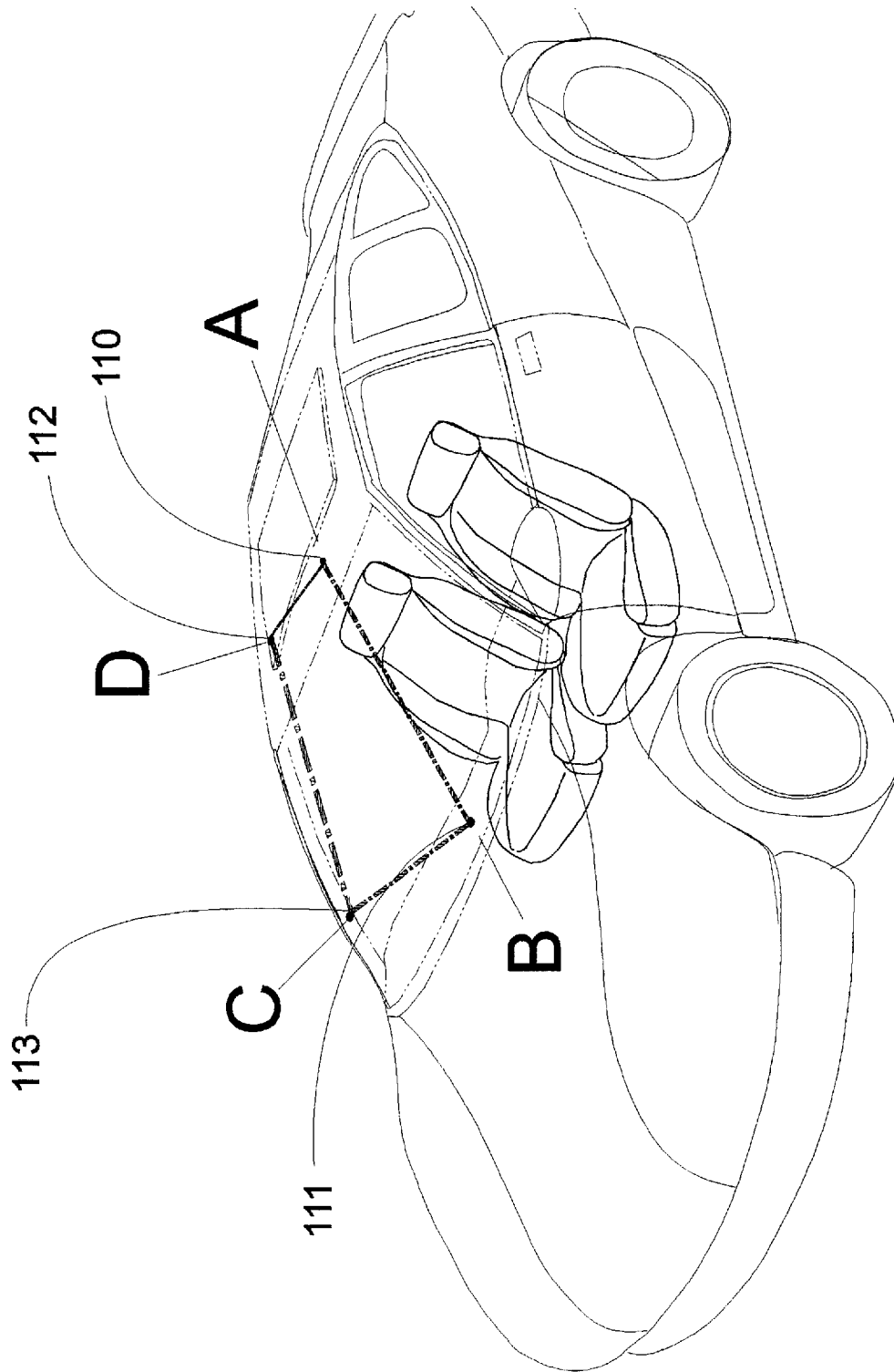


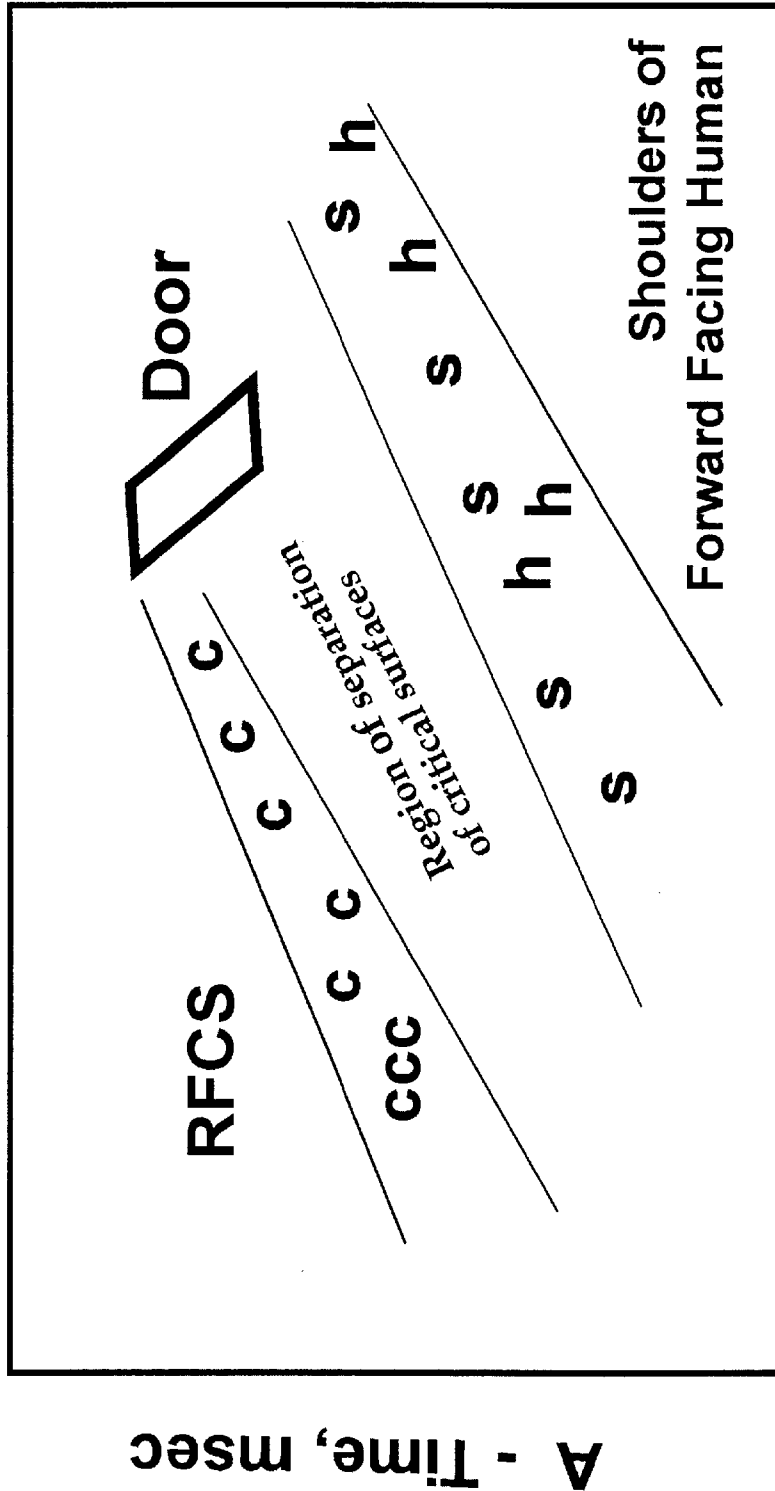
FIG. 9

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B - Time, msec

FIG. 10

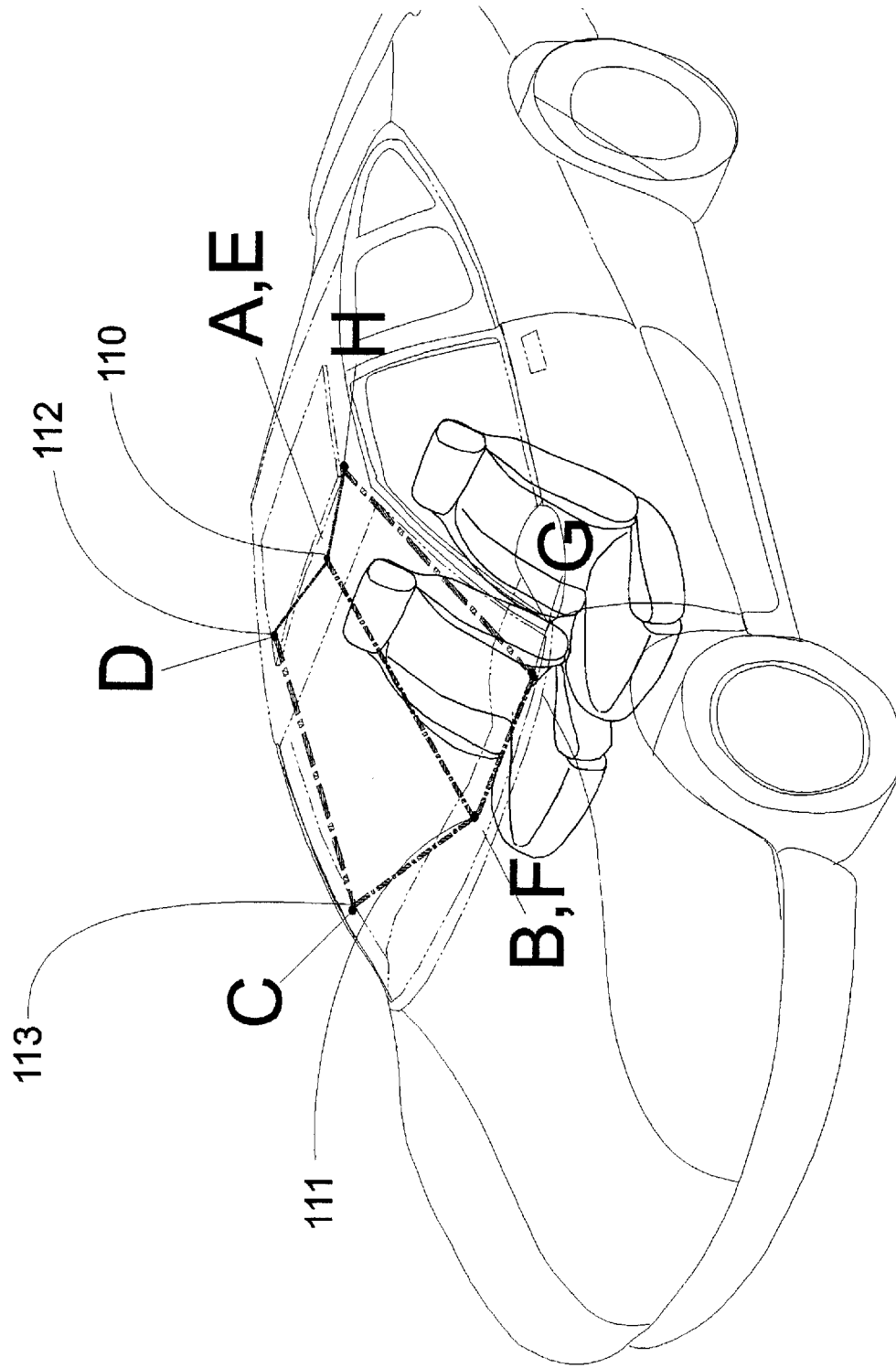
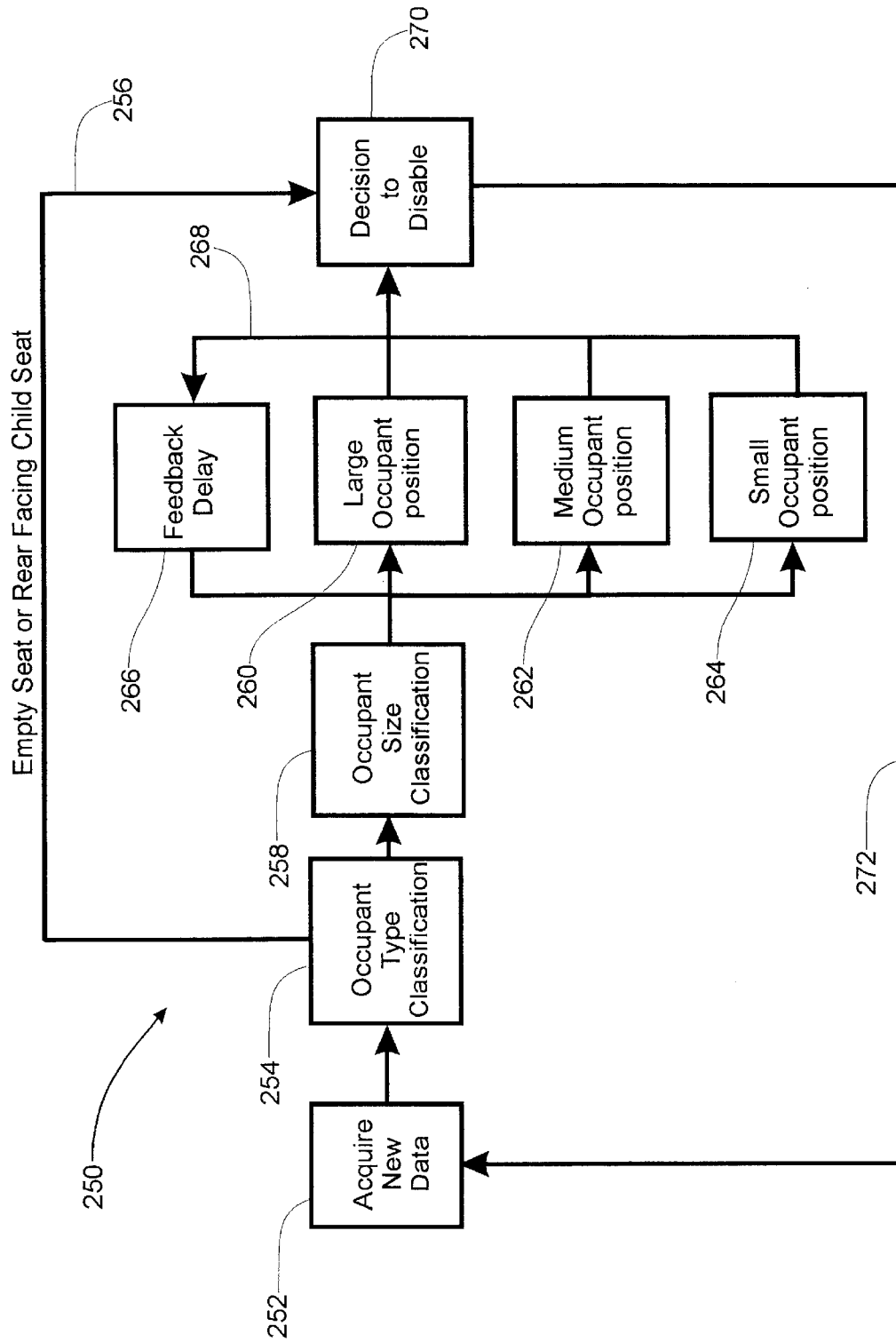


FIG. 11





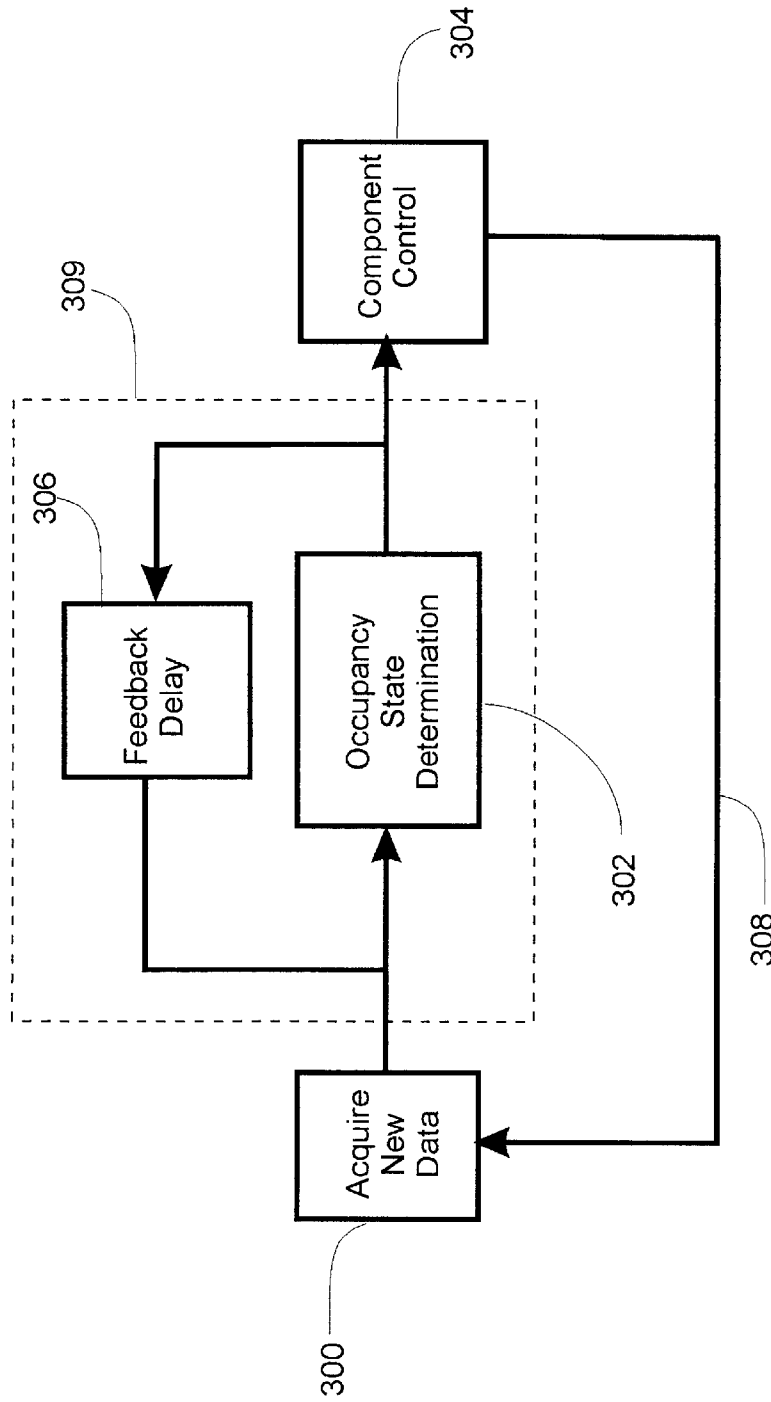


FIG. 13

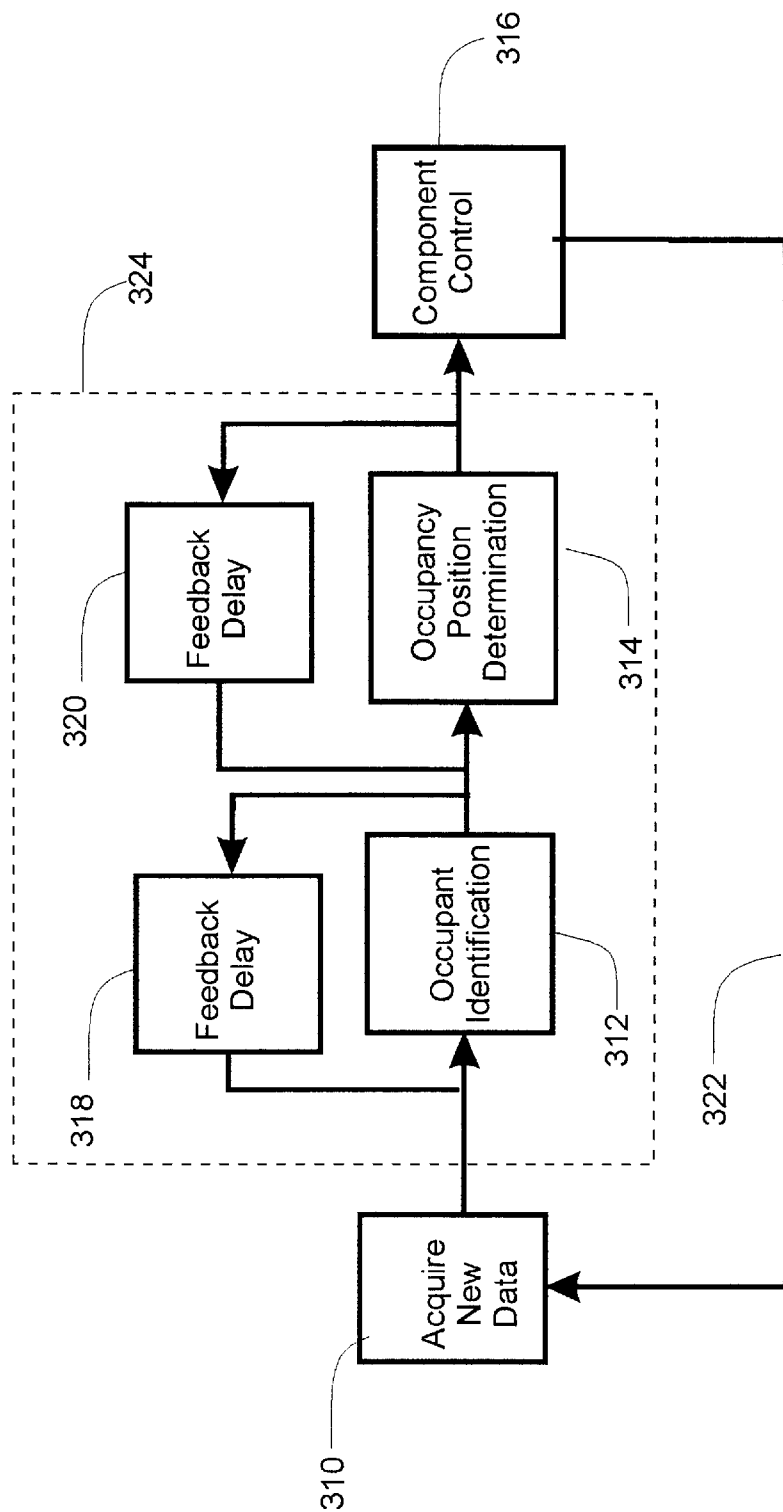


FIG. 14

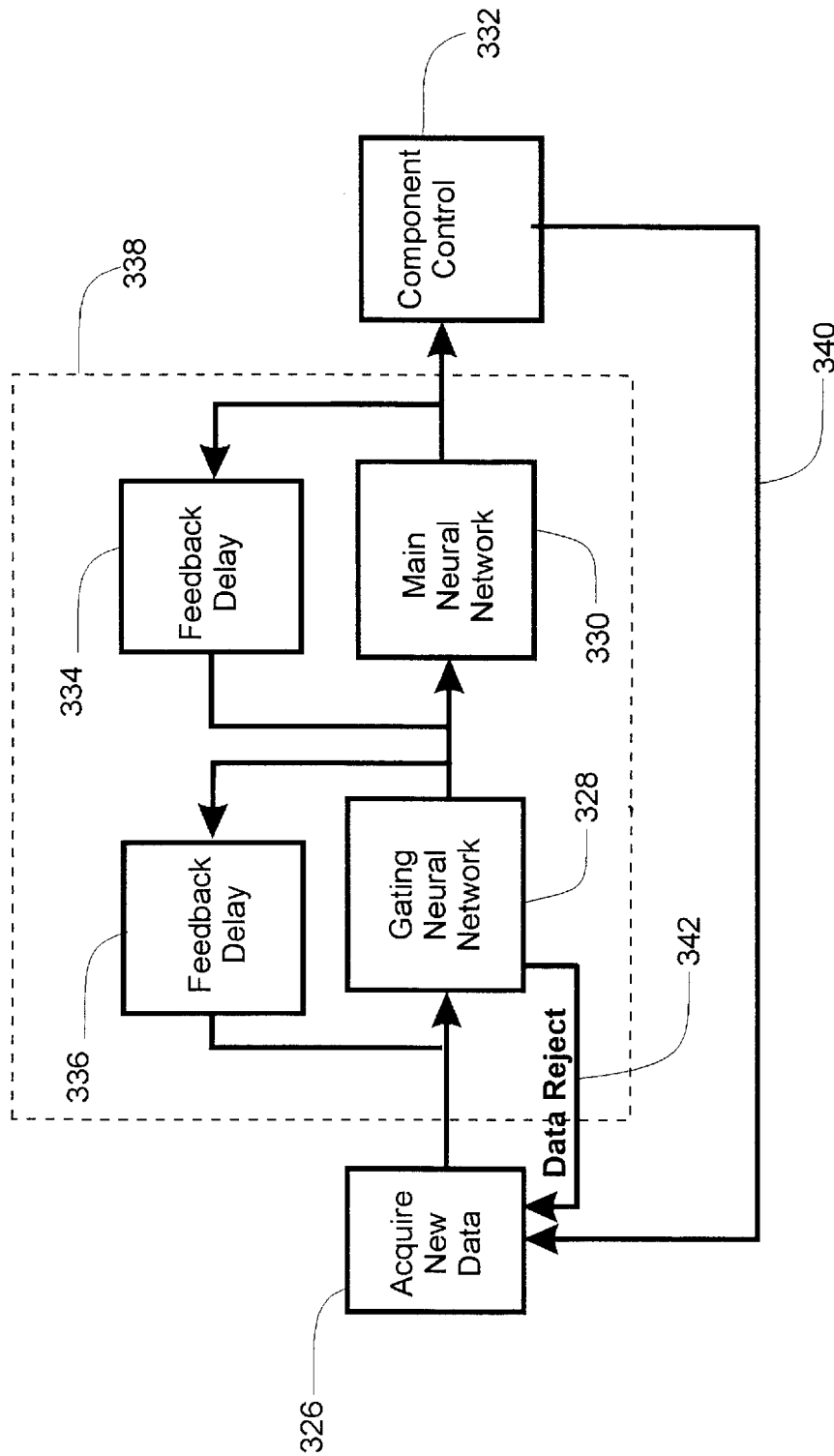


FIG. 15

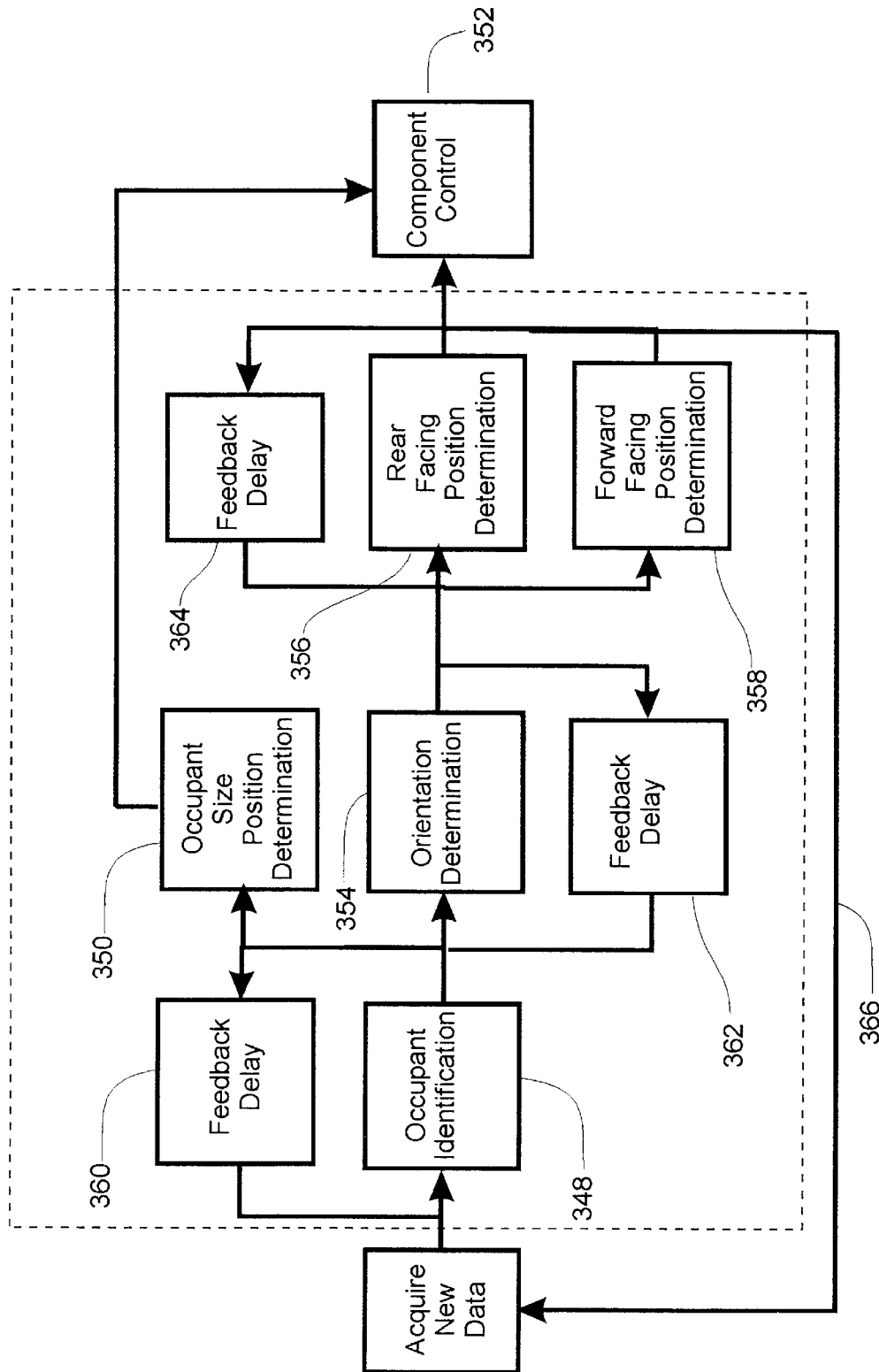


FIG. 16

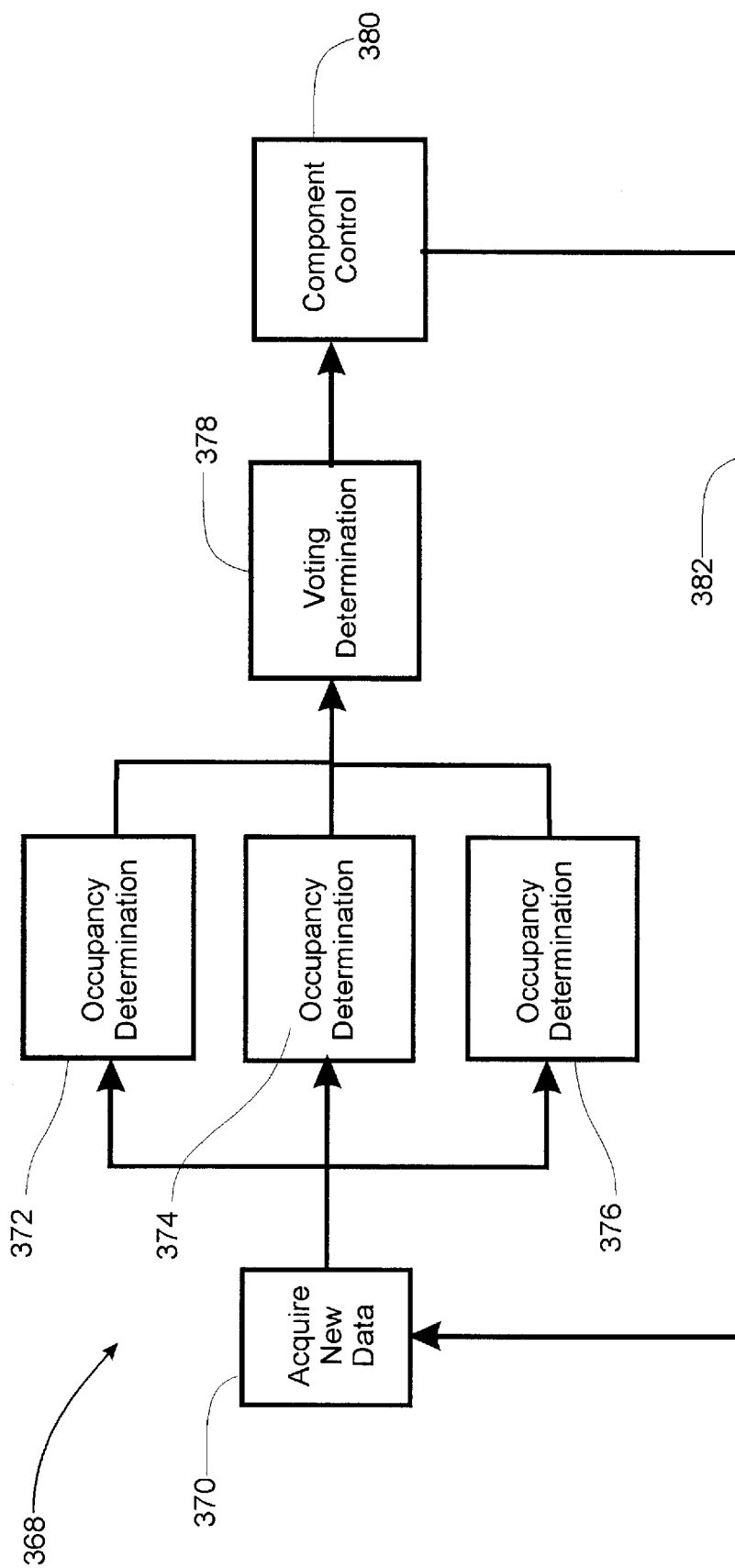


FIG. 17

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**Subject Classification**

Class	Instances	Weight Category	State
ES	Empty Seat	<10 lb	Empty
FFA	Normally Seated Adult	> 05 lb	Enable
FFC	Normally Seated Child	<10, 105> lb	Enable
FFC	Normally Positioned Forward Facing Child Seat	<10, 45> lb	Enable
OOP	Out-of-position Adult	>105 lb	Disable
OOP	Out-of-position Child	<105 lb	Disable
OOP	Out-of-position Forward Facing Child Seat	<10, 45> lb	Disable
RFS	Rearward Facing Child Seat	<10, 45> lb	Disable
RFS	Rearward Facing Infant Seat	<10, 45> lb	Disable

*FIG. 18*

### Categorization of Human Subjects

Weight Range kg (lb)		Height Range m (in)	
<b>Child</b>			
	<11,25>(<24,55>)	<0.95,1.15>(<3'1",3'9">)	<1.10,1.30>(<3'7",4'3">)
		C11	C12
	<22,36>(<48,79>)	C21	C22
	<33,47>(<73,103>)	C31	C32
<b>Adult</b>		<1.45,1.65>(<49,555'>)	<1.60,1.80>(<53,511'5'>)
	<45,70>(<99,154>)	A11	A12
	<65,90>(<143,198>)	A21	A22
	<85,110>(<187,242>)	A31	A32
			A13
			A23
			A33
			<1.25,1.45>(<4'1",4'9">)
			C13
			C23
			C33
			<1.75,1.95>(<59,655'>)

All Human Subjects are to wear light clothes (typically slacks and T-shirt) on entry.  
Other types of clothing to be provided by ATI

### Child Surrogates

<b>Doll</b>		Baby=0.50m (approx. 20")	Infant=0.75m (approx. 30")	Child=1.20m (approx. 48")
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*FIG. 19*

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**Rearward Facing Infant Seats**

<b>Designation</b>	<b>Child Seat</b>	<b>Attributes</b>
Training	Arriva	base, hood
Independent	Assura565	hood
Training	Baby-Safe	-
Training	Century 590	base, hood
Training	Evenflo Discovery	base, Tbar
Training	Evenflo Joyride (new)	hood
Independent	Evenflo Joyride (old)	-
Training	GerryGuard	base
Validation	Kolcraft Travelabout	base, Tbar
Training	Rock-n-Ride	-
Training	TLC	-

*FIG. 20*



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**Rearward Facing Child Seat**

<b>Designation</b>	<b>Child Seat</b>	<b>Attributes</b>
Training	CenturyI000	-
Validation	Century 2000 STE	-
Training	CenturyOvation	-
Training	Century Smartmove 5T	table
Training	Champion	table
Training	Fisher Price Child Seat	table
Training	Touriva	-
Training	Ultara	table
Training	Vario Exclusive	table

*FIG. 21*

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## Forward Facing Child and Booster Seats

Designation	Child Seat	Attributes
Training	Century1000	-
Validation	Century 2000 STE	-
Training	CenturyOvation	-
Validation	Century Smartmove 5T	table
Training	Champion	table
Validation	Fisher Price Booster	-
Training	Fisher Price Child Seat	table
Training	Gerry Booster	table
Training	Touriva	-
Training	Ultara	table
Training	Vario Exclusiv	table

*FIG. 22*

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Vehicle Configuration Series

Con fig	Seat Track (+/- .05")										Seatback Recline (+/- 2°)										Windows									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
A	0	0	2	2	2	4	4	6	6	6	0	18	4	12	20	2	20	0	8	16	D	D	U	U	D	D	U	U	D	D
B	1	1	3	3	3	5	5	7	7	7	2	20	0	8	16	0	18	4	12	20	U	U	D	D	U	D	D	U	U	U
C	0	0	2	2	4	4	4	6	6	6	5	15	4	16	0	15	20	2	10	18	U	U	D	D	U	D	D	U	U	U
D	1	1	3	3	5	5	5	7	7	7	4	16	5	15	2	10	18	0	15	20	D	D	U	U	D	D	U	U	D	D
E	0	0	0	2	2	2	4	4	6	6	0	8	16	4	12	20	2	20	0	18	D	D	U	U	D	D	U	U	D	D
F	1	1	1	3	3	3	5	5	7	7	4	12	20	0	8	16	0	18	2	20	U	U	D	D	U	D	D	U	U	U
G	0	0	2	2	2	4	4	4	6	6	4	16	2	20	2	10	18	0	15	20	U	U	D	D	U	D	D	U	U	U
H	1	1	3	3	3	5	5	5	7	7	2	20	4	16	0	15	20	2	10	18	D	D	U	U	D	D	U	U	D	D

FIG. 23A

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Vehicle Configuration Series

Con fig	Visor										Convertible Top									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
A	U	D	U	D	S	U	D	U	D	S	U	U	U	U	U	D	D	D	D	D
B	D	U	D	U	S	D	U	D	U	S	D	D	D	D	D	U	U	U	U	U
C	U	D	S	U	D	U	D	S	U	D	D	D	D	D	D	U	U	U	U	U
D	D	U	S	D	U	D	U	S	D	U	U	U	U	U	U	D	D	D	D	D
E	D	U	D	S	D	U	D	S	U	D	U	U	U	U	U	D	D	D	U	U
F	U	D	U	S	D	U	D	S	U	D	D	D	D	D	D	U	U	U	U	U
G	U	S	D	U	D	U	D	U	S	D	D	D	D	D	D	U	U	U	U	U
H	D	S	U	D	U	D	U	D	S	U	U	U	U	U	U	D	D	D	D	D

FIG. 23B

**Sequence for Child Seat Training Data Collection:**

Start object in center of the seat. Trainer has both hands on the steering wheel;  
With a smooth motion, push the object fully outboard, then pull it fully inboard, then push it to center position, then put hands back on the steering wheel;  
With a smooth motion, rotate the object 45 degrees outboard, the rotate 45 degrees inboard, then rotate back to center, then put hands back on the steering wheel;

**Sequence for Out-of-Position Forward Facing Child Seat Training Data Collection**

Start with object in the center line, leaning onto the Instrument Panel;  
With a smooth motion, push the object fully outboard, then pull it fully inboard, then push it to the center;  
Repeat this sequence with a 150 mm (6") gap between the object and the Instrument Panel; Apply small ( $\pm 10^\circ$ ) rotations.  
Repeat this sequence with a 300 mm (12") gap between the object and the Instrument Panel; Apply small ( $\pm 10^\circ$ ) rotations.

*FIG. 23C*

**Sequence for Human Subject Training Data Collection:**

Lean forward and outboard such that head and/or shoulders touch the Fire line;  
Gently traverse inboard while carefully following the Fire line until the center of the vehicle is reached;  
Lean halfway back towards the seatback and traverse outboard up against the side window. Rotate torso while doing so;  
Lean back into the seat and traverse inboard towards the center. Rotate torso while doing so;  
Sit back in the seat; "operate" radio controls, glove box, window, or seat controls; assume a brace posture;  
Do *not* cross the Fire line with head and/or shoulders at any time.

**Sequence for Out-of-Position Human Subject Training Data Collection:**

Lean forward and outboard such that head and/or shoulders touch the Instrument Panel;  
Gently traverse inboard towards the center console;  
Move back 150 mm (6") and gently traverse back to the most outboard position;  
Move back 300 mm (12") and gently traverse back to the center console;  
"Operate" radio controls and glovebox while head and/or shoulders remain in front of the Fire line.

*FIG. 23D*

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Network Training Set Collection Matrix (Vehicle E)

Rev 1.1

#	Class	Subject/Object	Attributes	Actions	Config	Belt	Conditions
1	ES	None	None	Motions of track and recline	(A)	N.A.	Ambient
2	FFA	A22	Medium Clothes, Magazine	Motions in safe seating area	B	Yes	Ambient
3	OOP	A22	Medium Clothes	Motions in NFZ	C	No	Ambient
4	FFC	Century 1000	Infant Doll	Motions in safe seating area	D	No	Ambient
5	RFS	Century 1000	Baby Doll	Motions in entire seating area	E	No	Ambient
6	ES	None	Beaded Cover	Motions of track and recline	(F)	N.A.	Ambient
7	FFA	A11	Medium Clothes	Motions in safe seating area	G	Yes	Ambient
8	OOP	Touriva	Infant Doll, Blanket	Motions in NFZ	H	No	Ambient
9	FFC	Touriva	Infant Doll, Blanket	Motions in safe seating area	A	No	Ambient
10	RFS	Century 590	Baby Doll, Hood	Motions in entire seating area	B	No	Ambient
11	ES	None	Fabric Cover	Motions of track and recline	(C)	N.A.	Ambient
12	FFA	A33	Medium Clothes, Newspaper	Motions in safe seating area	D	No	Ambient
13	OOP	A33	Medium Clothes	Motions in NFZ	E	Yes	Ambient
14	FFC	C22	Medium Clothes	Motions in safe seating area	F	No	Ambient
15	RFS	Touriva	Baby Doll, Blanket	Motions in entire seating area	G	No	Ambient
16	ES	None	Blanket	Motions of track and recline	(H)	N.A.	Ambient
17	FFA	A21	Heavy Clothes	Motions in safe seating area	A	No	Ambient
18	OOP	C11	Heavy Clothes	Motions in NFZ (standing)	B	No	Ambient
19	FFC	C11	Heavy Clothes	Motions in safe seating area	C	No	Ambient

FIG. 24A



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20	RFS	TLC	Baby Doll	Motions in entire seating area	D	No	Ambient
21	ES	None	None	Motions of track and recline	(E)	N.A.	Solar Heat
22	FFA	A12	Light Clothes, Magazine	Motions in safe seating area	F	Yes	Solar Heat
23	OOP	A12	Light Clothes	Motions in NFZ	G	No	Solar Heat
24	FFC	Champion	Infant Doll	Motions in safe seating area	H	No	Solar Heat
25	RFS	Champion	Baby Doll	Motions in entire seating area	A	No	Solar Heat
26	ES	None	Beaded Cover	Motions of track and recline	(B)	N.A.	Solar Heat
27	FFA	A23	Light Clothes	Motions in safe seating area	C	Yes	Solar Heat
28	OOP	Vario Exclusive	Child Doll	Motions in NFZ	D	No	Solar Heat
29	FFC	Vario Exclusive	Child Doll, Blanket	Motions in safe seating area	E	No	Solar Heat
30	RFS	Joyride (new)	Baby Doll	Motions in entire seating area	F	No	Solar Heat
31	ES	None	Fabric Cover	Motions of track and recline	(G)	N.A.	Solar Heat
32	FFA	A32	Light Clothes, Newspaper	Motions in safe seating area	H	No	Solar Heat
33	OOP	A32	Light Clothes	Motions in NFZ	A	Yes	Solar Heat
34	FFC	C33	Light Clothes	Motions in safe seating area	B	No	Solar Heat
35	RFS	Ultara	Baby Doll, Blanket	Motions in entire seating area	C	No	Solar Heat
36	ES	None	Blanket	Motions of track and recline	(D)	N.A.	Solar Heat
37	FFA	A22	Medium Clothes	Motions in safe seating area	E	No	Solar Heat
38	OOP	C21	Medium Clothes	Motions in NFZ	F	No	Solar Heat
39	FFC	C21	Medium Clothes	Motions in safe seating area	G	No	Solar Heat
40	RFS	Arriva	Baby Doll, Hood	Motions in entire seating area	H	No	Solar Heat
41	ES	None	Handbag	Motions of track and recline	(H)	N.A.	Ambient
42	FFA	A11	Heavy Clothes, Magazine	Motions in safe seating area	G	Yes	Ambient

FIG. 24B

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43	OOP	A11	Heavy Clothes	Motions in NFZ	F	No	Ambient
44	FFC	Gerry Booster	Infant Doll	Motions in safe seating area	E	No	Ambient
45	RFS	Fisher Price CS	Baby Doll	Motions in entire seating area	D	No	Ambient
46	ES	None	Beaded Cover, Handbag	Motions of track and recline	(C)	N.A.	Ambient
47	FFA	A33	Heavy Clothes	Motions in safe seating area	B	Yes	Ambient
48	OOP	Ultara	Infant Doll, Blanket	Motions in NFZ	A	No	Ambient
49	FFC	Ultara	Infant Doll, Blanket	Motions in safe seating area	H	No	Ambient
50	RFS	Baby Safe	Baby Doll, Handle up	Motions in entire seating area	G	No	Ambient
51	ES	None	Fabric Cover, Handbag	Motions of track and recline	(F)	N.A.	Ambient
52	FFA	A21	Heavy Clothes, Newspaper	Motions in safe seating area	E	No	Ambient
53	OOP	A21	Heavy Clothes	Motions in NFZ	D	Yes	Ambient
54	FFC	C12	Heavy Clothes	Motions in safe seating area	C	No	Ambient
55	RFS	Vario Exclusive	Baby Doll, Blanket	Motions in entire seating area	B	No	Ambient
56	ES	None	Blanket, Handbag	Motions of track and recline	(A)	N.A.	Ambient
57	FFA	A12	Rain Clothes	Motions in safe seating area	H	No	Ambient
58	OOP	C23	Rain Clothes	Motions in NFZ	G	No	Ambient
59	FFC	C23	Rain Clothes	Motions in safe seating area	F	No	Ambient
60	RFS	Rock'n'Ride	Baby Doll	Motions in entire seating area	E	No	Ambient
61	ES	None	None	Motions of track and recline	(D)	N.A.	Ambient
62	FFA	A23	Light Clothes, Magazine	Motions in safe seating area	C	Yes	Air Conditioner Air Conditioner

**FIG. 24C**

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63	OOP	A23	Light Clothes	Motions in NFZ	B	No	Air Conditioner
64	FFC	Century Ovation	Infant Doll	Motions in safe seating area	A	No	Air Conditioner
65	RFS	Century Ovation	Baby Doll	Motions in entire seating area	H	No	Air Conditioner
66	ES	None	Beaded Cover	Motions of track and recline	(G)	N.A.	Air Conditioner
67	FFA	A32	Light Clothes	Motions in safe seating area	F	Yes	Air Conditioner
68	OOP	Fisher Price CS	Child Doll	Motions in NFZ	E	No	Air Conditioner
69	FFC	Fisher Price CS	Child Doll, Blanket	Motions in safe seating area	D	No	Air Conditioner
70	RFS	Gerry Guard	Baby Doll	Motions in entire seating area	C	No	Air Conditioner
71	ES	None	Fabric Cover	Motions of track and recline	(B)	N.A.	Air Conditioner
72	FFA	A22	Light Clothes, Newspaper	Motions in safe seating area	A	No	Air Conditioner
73	OOP	A22	Light Clothes	Motions in NFZ	H	Yes	Air Conditioner
74	FFC	C32	Light Clothes	Motions in safe seating area	G	No	Air Conditioner
75	RFS	Smartmove 5T	Baby Doll, Blanket	Motions in entire seating area	F	No	Air Conditioner
76	ES	None	Blanket	Motions of track and recline	(E)	N.A.	Air Conditioner
77	FFA	A11	Medium Clothes	Motions in safe seating area	D	No	Air Conditioner
78	OOP	C22	Medium Clothes	Motions in NFZ	C	No	Air Conditioner
79	FFC	C22	Medium Clothes	Motions in safe seating area	B	No	Air Conditioner
80	RFS	Discovery	Baby Doll, Handle up	Motions in entire seating area	A	No	Air Conditioner
81	ES	None	Pizza Box	Motions of track and recline	(B)	N.A.	Ambient
82	FFA	A33	Rain Clothes, Magazine	Motions in safe seating area	A	Yes	Ambient
83	OOP	A33	Rain Clothes	Motions in NFZ	D	Yes	Ambient
84	FFC	Champion	Infant Doll	Motions in safe seating area	C	No	Ambient

FIG. 24D

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85	RFS	Champion	Baby Doll	Motions in entire seating area	F	No	Ambient
86	ES	None	Beaded Cover, Pizza Box	Motions of track and recline	(E)	N.A.	Ambient
87	FFA	A21	Rain Clothes	Motions in safe seating area	H	Yes	Ambient
88	OOP	Vario Exclusive	Child Doll, Blanket	Motions in NFZ	G	No	Ambient
89	FFC	Vario Exclusive	Child Doll, Blanket	Motions in safe seating area	B	No	Ambient
90	RFS	Joyride (new)	Baby Doll, Hood	Motions in entire seating area	A	No	Ambient
91	ES	None	Fabric Cover, Pizza Box	Motions of track and recline	(D)	N.A.	Ambient
92	FFA	A12	Rain Clothes, Newspaper	Motions in safe seating area	C	No	Ambient
93	OOP	A12	Rain Clothes	Motions in NFZ	F	No	Ambient
94	FFC	C23	Rain Clothes	Motions in safe seating area	E	No	Ambient
95	RFS	Ultara	Baby Doll, Blanket	Motions in entire seating area	H	No	Ambient
96	ES	None	Blanket, Pizza Box	Motions of track and recline	(G)	N.A.	Ambient
97	FFA	A23	Light Clothes	Motions in safe seating area	B	No	Ambient
98	OOP	C32	Light Clothes	Motions in NFZ	A	No	Ambient
99	FFC	C32	Light Clothes	Motions in safe seating area	D	No	Ambient
100	RFS	Arriva	Baby Doll, Hood	Motions in entire seating area	C	No	Ambient
101	ES	None	None	Motions of track and recline	(F)	N.A.	Car Heat
102	FFA	A32	Light Clothes, Magazine	Motions in safe seating area	E	Yes	Car Heat
103	OOP	A32	Light Clothes	Motions in NFZ	H	Yes	Car Heat
104	FFC	Century 1000	Infant Doll	Motions in safe seating area	G	No	Car Heat
105	RFS	Century 1000	Baby Doll	Motions in entire seating area	B	No	Car Heat
106	ES	None	Beaded Cover	Motions of track and recline	(A)	N.A.	Car Heat

*FIG. 24E*

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107	FFA	A22	Rain Clothes	Motions in safe seating area	D	Yes	Car Heat
108	OOP	Vario Exclusive	Infant Doll	Motions in NFZ	C	No	Car Heat
109	FFC	Touriva	Infant Doll, Blanket	Motions in safe seating area	F	No	Car Heat
110	RFS	Century 590	Baby Doll	Motions in entire seating area	E	No	Car Heat
111	ES	None	Fabric Cover	Motions of track and recline	(H)	N.A.	Car Heat
112	FFA	A11	Light Clothes, Newspaper	Motions in safe seating area	G	No	Car Heat
113	OOP	A11	Light Clothes	Motions in NFZ	B	No	Car Heat
114	FFC	C32	Light Clothes	Motions in safe seating area	A	No	Car Heat
115	RFS	Touriva	Baby Doll, Blanket	Motions in entire seating area	D	No	Car Heat
116	ES	None	Blanket	Motions of track and recline	(C)	N.A.	Car Heat
117	FFA	A33	Heavy Clothes	Motions in safe seating area	F	No	Car Heat
118	OOP	C22	Heavy Clothes	Motions in NFZ	E	No	Car Heat
119	FFC	C22	Heavy Clothes	Motions in safe seating area	H	No	Car Heat
120	RFS	TLC	Baby Doll	Motions in entire seating area	G	No	Car Heat
121	ES	None	Attaché Case (flat)	Motions of track and recline	(G)	N.A.	Ambient
122	FFA	A21	Heavy Clothes, Magazine	Motions in safe seating area	H	Yes	Ambient
123	OOP	A21	Heavy Clothes	Motions in NFZ	E	Yes	Ambient
124	FFC	Century Ovation	Infant Doll	Motions in safe seating area	F	No	Ambient
125	RFS	Century Ovation	Baby Doll	Motions in entire seating area	C	No	Ambient
126	ES	None	Beaded Cover, Attaché Case	Motions of track and recline	(D)	N.A.	Ambient
127	FFA	A12	Rain Clothes	Motions in safe seating area	A	Yes	Ambient
128	OOP	Fisher Price CS	Infant Doll, Blanket	Motions in NFZ	B	No	Ambient

FIG. 24F

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129	FFC	Fisher Price CS	Infant Doll	Motions in safe seating area	G	No	Ambient
130	RFS	Gerry Guard	Baby Doll, Handle up	Motions in entire seating area	H	No	Ambient
131	ES	None	Fabric Cover, Attaché Case	Motions of track and recline	(E)	N.A.	Ambient
132	FFA	A23	Heavy Clothes, Newspaper	Motions in safe seating area	F	No	Ambient
133	OOP	A23	Heavy Clothes	Motions in NFZ	C	No	Ambient
134	FFC	C11	Heavy Clothes	Motions in safe seating area	D	No	Ambient
135	RFS	Smartmove 5T	Baby Doll, Blanket	Motions in entire seating area	A	No	Ambient
136	ES	None	Blanket, Attaché Case	Motions of track and recline	(B)	N.A.	Ambient
137	FFA	A32	Rain Clothes	Motions in safe seating area	G	No	Ambient
138	OOP	C33	Rain Clothes	Motions in NFZ	H	No	Ambient
139	FFC	C33	Rain Clothes	Motions in safe seating area	E	No	Ambient
140	RFS	Discovery	Baby Doll, Handle up	Motions in entire seating area	F	No	Ambient
141	ES	None	Hand Bag	Motions of track and recline	(C)	N.A.	Solar Heat
142	FFA	A22	Medium Clothes, Magazine	Motions in safe seating area	D	Yes	Solar Heat
143	OOP	A22	Heavy Clothes	Motions in NFZ	A	Yes	Solar Heat
144	FFC	Gerry Booster	Child Doll	Motions in safe seating area	B	No	Solar Heat
145	RFS	Fisher Price CS	Baby Doll	Motions in entire seating area	G	No	Solar Heat
146	ES	None	Beaded Cover, Hand Bag	Motions of track and recline	(H)	N.A.	Solar Heat

*FIG. 24G*

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147	FFA	A11	Medium Clothes	Motions in safe seating area	E	Yes	Solar Heat
148	OOP	Vario Exclusive	Infant Doll	Motions in NFZ	F	No	Solar Heat
149	FFC	Ultara	Infant Doll, Blanket	Motions in safe seating area	C	No	Solar Heat
150	RFS	Baby Safe	Baby Doll	Motions in entire seating area	D	No	Solar Heat
151	ES	None	Fabric Cover, Hand Bag	Motions of track and recline	(A)	N.A.	Solar Heat
152	FFA	A33	Medium Clothes, Newspaper	Motions in safe seating area	B	No	Solar Heat
153	OOP	A33	Medium Clothes	Motions in NFZ	G	No	Solar Heat
154	FFC	C33	Medium Clothes	Motions in safe seating area	H	No	Solar Heat
155	RFS	Vario Exclusive	Baby Doll, Blanket	Motions in entire seating area	E	No	Solar Heat
156	ES	None	Blanket, Hand Bag	Motions of track and recline	(F)	N.A.	Solar Heat
157	FFA	A21	Light Clothes	Motions in safe seating area	C	No	Solar Heat
158	OOP	C21	Light Clothes	Motions in NFZ	D	No	Solar Heat
159	FFC	C21	Light Clothes	Motions in safe seating area	A	No	Solar Heat
160	RFS	Rock'n'Ride	Baby Doll	Motions in entire seating area	B	No	Solar Heat

**FIG. 24H**



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**Network Independent Test Set Collection Matrix (Vehicle E)**  
**Rev 1.1 ( Under Construction )**

#	Class	Subject/ Object	Attributes	Actions	Config.	Belt	Conditions
1	ES			Motions of track and recline	(A)	N.A.	Ambient
2	FFA			Motions in safe seating area	B	Yes	Ambient
3	OOP			Motions in NFZ	C	No	Ambient
4	FFC			Motions in safe seating area	D	No	Ambient
5	RFS			Motions in entire seating area	E	No	Ambient
6	ES			Motions of track and recline	(F)	N.A.	Ambient
7	FFA			Motions in safe seating area	G	Yes	Ambient
8	OOP			Motions in NFZ	H	No	Ambient
9	FFC			Motions in safe seating area	A	No	Ambient
10	RFS			Motions in entire seating area	B	No	Ambient
11	ES			Motions of track and recline	(C)	N.A.	Ambient
12	FFA			Motions in safe seating area	D	No	Ambient
13	OOP			Motions in NFZ	E	Yes	Ambient
14	FFC			Motions in safe seating area	F	No	Ambient
15	RFS			Motions in entire seating area	G	No	Ambient
16	ES			Motions of track and recline	(H)	N.A.	Ambient
17	FFA			Motions in safe seating area	A	No	Ambient
18	OOP			Motions in NFZ (standing)	B	No	Ambient
19	FFC			Motions in safe seating area	C	No	Ambient
20	RFS			Motions in entire seating area	D	No	Ambient

*FIG. 25*

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**CHARACTERISTICS OF THE DATA SETS**

<b>DATA SET</b>	<b>CONFIGURATIONS</b>	<b>SETUPS</b>	<b>VECTORS</b>
TRAINING	130	1300	650,000
INDEPENDENT TEST	130	1300	195,000
VALIDATION	100	100	15,000

*FIG. 26*

DISTRIBUTION OF MAIN TRAINING SUBJECTS

OCCUPANCY	REPRESENTATION
EMPTY SEAT	10 %
HUMAN OCCUPANT	32 %
CHILD SEAT	58 %

FIG. 27

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**CHILD SEAT DISTRIBUTION**

<b>CHILD SEAT CONFIGURATION</b>	<b>REPRESENTATION</b>
FORWARD FACING CHILD SEAT	40 %
FORWARD FACING CHILD SEAT OUT OF-POSITION	4 %
REARWARD FACING CHILD SEAT	27 %
REARWARD FACING INFANT SEAT	29 %

*FIG. 28*

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**DISTRIBUTION OF ENVIRONMENTAL CONDITIONS**

<b>ENVIRONMENTAL CONDITION</b>	<b>REPRESENTATION</b>
AMBIENT	56 %
STATIC HEAT (SOLAR LAMP)	25 %
DYNAMIC HEAT (CAR HEAT)	13 %
DYNAMIC COOLING (CAR A C)	6 %

*FIG. 29*

**VALIDATION DATA DISTRIBUTION**

<b>OCCUPANCY</b>	<b>REPRESENTATION</b>
<b>EMPTY SEAT</b>	<b>8 %</b>
<b>HUMAN OCCUPANT</b>	<b>39 %</b>
<b>CHILD SEAT</b>	<b>53 %</b>

***FIG. 30***

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## HUMAN SUBJECT DISTRIBUTION

HUMAN OCCUPANT	REPRESENTATION	NORMALLY SEATED	OUT-OF-POSITION
CHILD AGE 3	15 %	50 %	50 %
CHILD AGE 6	15 %	50 %	50 %
ADULT 5 <sup>TH</sup> PERCENTILE FEMALE	23 %	67 %	33 %
ADULT 50 <sup>TH</sup> PERCENTILE MALE	23 %	67 %	33 %
ADULT 95 <sup>TH</sup> PERCENTILE MALE	23 %	67 %	33 %

FIG. 31



**CHILD SEAT DISTRIBUTION**

<b>CHILD SEAT CONFIGURATION</b>	<b>REPRESENTATION</b>
FORWARD FACING CHILD SEAT	11 %
FORWARD FACING BOOSTER SEAT	11 %
REARWARD FACING CHILD SEAT	38 %
REARWARD FACING INFANT SEAT	40 %

*FIG. 32*

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**DISTRIBUTION OF ENVIRONMENTAL CONDITIONS**

<b>ENVIRONMENTAL CONDITION</b>	<b>REPRESENTATION</b>
AMBIENT	63 %
STATIC HEAT (SOLAR LAMP)	13 %
DYNAMIC HEAT (CAR HEAT)	12 %
DYNAMIC COOLING (CAR AIR CONDITIONER)	12 %

*FIG. 33*

**U.S. Patent****Jun. 29, 2004****Sheet 44 of 50****US 6,757,602 B2****TRANSDUCER VOLUME**

<b>TRANS-DUCER</b>	<b>STARTING POINT</b>			<b>END POINT</b>		
	<b>SAMPLE</b>	<b>TIME (MS)</b>	<b>DISTANCE (MM)</b>	<b>SAMPLE</b>	<b>TIME (MS)</b>	<b>DISTANCE (MM)</b>
A	5	0.83	142	29	4.84	822
B	3	0.50	85	35	5.84	992
C	7	1.17	198	34	5.67	964
H	2	0.33	57	32	5.34	907

**FIG. 34**

**BASELINE NETWORK PERFORMANCE**

SELF TEST SUCCESS RATE	95.3 %
INDEPENDENT TEST SUCCESS RATE	94.5 %
VALIDATION TEST SUCCESS RATE	92.7 %

*FIG. 35*

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**PERFORMANCE PER OCCUPANCY SUBSET**

<b>OCCUPANCY</b>	<b>INDEPENDENT TEST</b>
EMPTY SEAT	96.1 %
NORMALLY SEATED ADULT	92.1 %
REARWARD FACING CHILD/INFANT SEAT	94.1 %
FORWARD FACING CHILD SEAT	96.9 %
OUT-OF-POSITION HUMAN/FFCS	93.0 %

*FIG. 36*

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**PERFORMANCE PER ENVIRONMENTAL CONDITIONS SUBSET**

<b>ENVIRONMENTAL CONDITION</b>	<b>INDEPENDENT TEST</b>
AMBIENT	95.4 %
LONG TERM HEAT (LAMP HEAT)	95.2 %
SORT TERM HEATING/COOLING (HVAC)	93.5 %

*FIG. 37*

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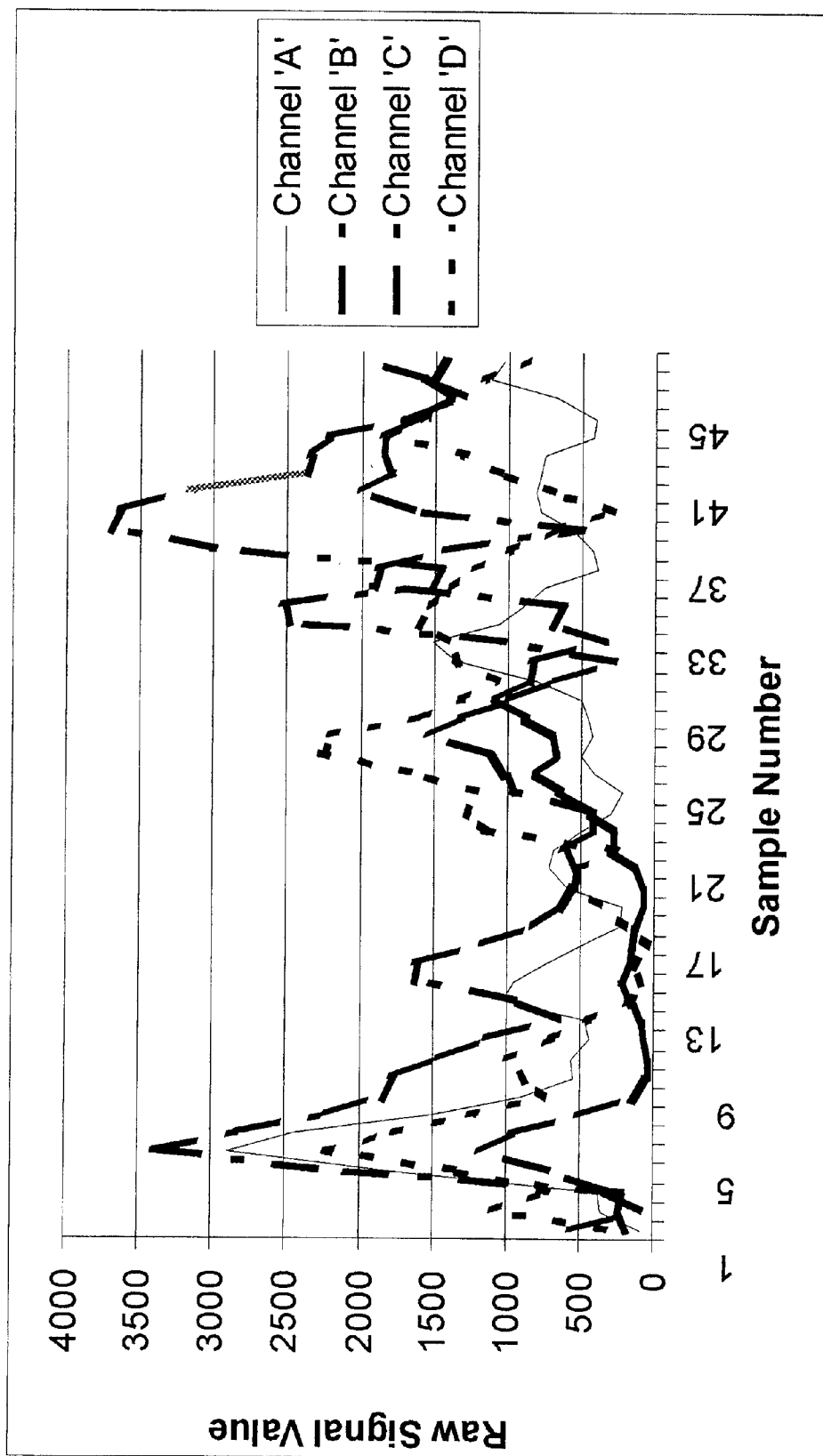


FIG. 38

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## NORMALIZATION STUDY RESULTS

NORMALIZATION METHOD	SELF TEST	INDEPENDENT TEST	VALIDATION TEST
A. WHOLE VECTOR (BASE)	95.3 %	94.5 %	92.7 %
B. PER CHANNEL	94.9 %	93.8 %	90.3 %
C. FIXED RANGE [0,4095]	95.6 %	90.3 %	88.3 %

*FIG. 39*



**U.S. Patent****Jun. 29, 2004****Sheet 50 of 50****US 6,757,602 B2****LOW THRESHOLD FILTER STUDY RESULTS**

<b>THRESHOLD LEVEL</b>	<b>SELF TEST</b>	<b>INDEPENDENT TEST</b>	<b>VALIDATION TEST</b>
NONE (BASE)	95.3 %	94.5 %	92.7 %
5% OF 4095	95.3 %	94.4 %	91.9 %
10% OF 4095	95.3 %	94.3 %	92.5 %
20% OF 4095	95.1 %	94.2 %	86.4 %

***FIG. 40***

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# SYSTEM FOR DETERMINING THE OCCUPANCY STATE OF A SEAT IN A VEHICLE AND CONTROLLING A COMPONENT BASED THEREON

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 09/853,118 filed May 10, 2001, now U.S. Pat. No. 6,445,988, which in turn is a continuation-in-part of U.S. patent application Ser. No. 09/474,147 filed Dec. 29, 1999, now U.S. Pat. No. 6,397,136, which claims the benefit of U.S. provisional patent application Ser. No. 60/136,163 filed May 27, 1999 and which turn is a continuation-in-part of U.S. patent application Ser. No. 09/382,406 filed Aug. 24, 1999, now U.S. Pat. No. 6,529,809, which in turn is a continuation-in-part of U.S. patent application Ser. No. 08/919,823 Filed Aug. 28, 1997, now U.S. Pat. No. 5,943,295, which in turn is a continuation-in-part of U.S. patent application Ser. No. 08/798,029 filed Feb. 6, 1997, now abandoned.

This application is related to: (i) U.S. Pat. No. 5,653,462 entitled "Vehicle Occupant Position and Velocity Sensor" filed Jul. 21, 1995, which is a continuation of U.S. patent application Ser. No. 08/040,978 filed Mar. 31, 1997, now abandoned, which in turn is a continuation of U.S. patent application Ser. No. 07/878,571 filed May 5, 1992, now abandoned; (ii) U.S. Pat. No. 5,829,782 entitled "Vehicle Interior Identification and Monitoring System" filed May 9, 1994; (iii) U.S. Pat. No. 5,845,000 entitled "Optical Identification and Monitoring System Using Pattern Recognition for Use with Vehicles" filed Jun. 7, 1995; (iv) U.S. Pat. No. 5,822,707 entitled "Automatic Vehicle Seat Adjuster" filed Jun. 7, 1995; (v) U.S. Pat. No. 5,748,473 entitled "Automatic Vehicle Seat Adjuster" filed Jun. 7, 1995; and (vi) U.S. Pat. No. 5,835,613 entitled "Optical Identification and Monitoring System Using Pattern Recognition for use with Vehicles" filed Jun. 7, 1995, which are all incorporated by reference herein.

## FIELD OF THE INVENTION

The present invention relates generally to the field of determining the occupancy state of the vehicle which entails sensing, detecting, monitoring and/or identifying various objects, and parts thereof, which are located within the passenger compartment of the vehicle. The occupancy state is a broad or narrow description of the state or condition of one or more occupying items in the vehicle. Thus, a determination of the occupancy state may include a determination of the type or class of any occupying items, the size of any occupying items, the position of any occupying item including the orientation of occupying items, the identification of any occupying items and/or the status of any occupying items (whether the occupying items are conscious or unconscious). The determination of the occupancy state is used to control a vehicular component.

In particular, the present invention relates to an efficient and highly reliable system for evaluating the occupancy of a vehicle by detecting the presence and optionally orientation of objects in the seats of the passenger compartment, e.g., a rear facing child seat (RFCS) situated in the passenger compartment in a location where it may interact with a deploying occupant protection apparatus, such as an airbag, and/or for detecting an out-of-position occupant. The system permits the control and selective suppression of deployment of the occupant protection apparatus when the deployment

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may result in greater injury to the occupant than the crash forces themselves. This is accomplished in part through a specific placement of transducers of the system, the use of a pattern recognition system, possibly a trained neural network and combinations of neural networks called modular neural, voting or ensemble neural networks, support vector machines, cellular neural networks and/or a novel analysis of the signals from the transducers.

## BACKGROUND OF THE INVENTION

### 1. Prior Art on Sensing of Out-of-Position Occupants and Rear Facing Child Seats

Whereas thousands of lives have been saved by airbags, a large number of people have also been injured, some seriously, by the deploying airbag, and thus significant improvements to the airbag system are necessary. As discussed in detail in one or more of the patents and patent applications cross-referenced above, for a variety of reasons, vehicle occupants may be too close to the airbag before it deploys and can be seriously injured or killed as a result of any deployment thereof. Also, a child in a rear facing child seat which is placed on the right front passenger seat is in danger of being seriously injured if the passenger airbag deploys. For these reasons and, as first publicly disclosed in Breed, D. S. "How Airbags Work" presented at the International Conference on Seatbelts and Airbags in 1993, in Canada, occupant position sensing and rear facing child seat detection is required in order to minimize the damages caused by deploying airbags. It also may be required in order to minimize the damage caused by the deployment of other types of occupant protection and/or restraint devices which might be installed in the vehicle

Initially, these systems will solve the out-of-position occupant and the rear facing child seat problems related to current airbag systems and prevent unneeded and unwanted airbag deployments when a front seat is unoccupied. However, airbags are now under development to protect rear seat occupants in vehicle crashes and all occupants in side impacts. A system is therefore needed to detect the presence of occupants, determine if they are out-of-position, defined below, and to identify the presence of a rear facing child seat in the rear seat. Future automobiles are expected to have eight or more airbags as protection is sought for rear seat occupants and from side impacts. In addition to eliminating the disturbance and possible harm of unnecessary airbag deployments, the cost of replacing these airbags will be excessive if they all deploy in an accident needlessly.

Inflators now exist which will adjust the amount of gas flowing to or from the airbag to account for the size and position of the occupant and for the severity of the accident. The vehicle identification and monitoring system (VIMS) discussed in U.S. Pat. Nos. 5,829,782, and 5,943,295 among others, will control such inflators based on the presence and position of vehicle occupants or of a rear facing child seat. The instant invention is concerned with the process of adapting the vehicle interior monitoring systems to a particular vehicle model and achieving a high system accuracy and reliability as discussed in greater detail below as well as the resulting pattern recognition system architecture.

The automatic adjustment of the deployment rate of the airbag based on occupant identification and position and on crash severity has been termed "smart airbags". Central to the development of smart airbags is the occupant identification and position determination systems described in the above-referenced patents and patent applications and to the methods described herein for adapting those systems to a particular vehicle model. To complete the development of smart airbags, an anticipatory crash detecting system such as

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disclosed in U.S. Pat. No. 6,343,810 is also desirable. Prior to the implementation of anticipatory crash sensing, the use of a neural network smart crash sensor which identifies the type of crash and thus its severity based on the early part of the crash acceleration signature should be developed and thereafter implemented. U.S. Pat. No. 5,684,701 (Breed) describes a crash sensor based on neural networks. This crash sensor, as with all other crash sensors, determines whether or not the crash is of sufficient severity to require deployment of the airbag and, if so, initiates the deployment. A neural network based on a smart airbag crash sensor could also be designed to identify the crash and categorize it with regard to severity thus permitting the airbag deployment to be matched not only to the characteristics and position of the occupant but also the severity and timing of the crash itself as described in more detail in U.S. Pat. No. 5,943,295 referenced above.

The need for an occupant out-of-position sensor has also been observed by others and several methods have been described in certain U.S. patents for determining the position of an occupant of a motor vehicle. However, no patents have been found that describe the methods of adapting such sensors to a particular vehicle model to obtain high system accuracy or to a resulting architecture combination of pattern recognition algorithms. Each of these systems will be discussed below and have significant limitations.

In White et al. (U.S. Pat. No. 5,071,160), for example, a single acoustic sensor and detector is described and, as illustrated, is disadvantageously mounted lower than the steering wheel. White et al. correctly perceive that such a sensor could be defeated, and the airbag falsely deployed, by an occupant adjusting the control knobs on the radio and thus they suggest the use of a plurality of such sensors. White et al. does not disclose where the such sensors would be mounted, other than on the instrument panel below the steering wheel, or how they would be combined to uniquely monitor particular locations in the passenger compartment and to identify the object(s) occupying those locations. The adaptation process to vehicles is not described nor is a combination of pattern recognition algorithms.

Mattes et al. (U.S. Pat. No. 5,118,134) describe a variety of methods for measuring the change in position of an occupant including ultrasonic, active or passive infrared radiation, microwave radar sensors, and an electric eye. The use of these sensors is to measure the change in position of an occupant during a crash and they use that information to assess the severity of the crash and thereby decide whether or not to deploy the airbag. They are thus using the occupant motion as a crash sensor. No mention is made of determining the out-of-position status of the occupant or of any of the other features of occupant monitoring as disclosed in the above-referenced patents and/or patent applications. It is interesting to note that nowhere does Mattes et al. discuss how to use a combination of ultrasonic sensors/transmitters to identify the presence of a human occupant and then to find his/her location in the passenger compartment or any pattern recognition algorithm let alone a combination of such algorithms.

The object of an occupant out-of-position sensor is to determine the location of the head and/or chest of the vehicle occupant in the passenger compartment relative to the occupant protection apparatus, such as an airbag, since it is the impact of either the head or chest with the deploying airbag which can result in serious injuries. Both White et al. and Mattes et al. disclose only lower mounting locations of their sensors which are mounted in front of the occupant such as on the dashboard or below the steering wheel. Both

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such mounting locations are particularly prone to detection errors due to positioning of the occupant's hands, arms and legs. This would require at least three, and preferably more, such sensors and detectors and an appropriate logic circuitry, or pattern recognition system, which ignores readings from some sensors if such readings are inconsistent with others, for the case, for example, where the driver's arms are the closest objects to two of the sensors. The determination of the proper transducer mounting locations, aiming and field angles and pattern recognition system architectures for a particular vehicle model are not disclosed in either White et al. or Mattes et al. and are part of the vehicle model adaptation process described herein.

White et al. also describe the use of error correction circuitry, without defining or illustrating the circuitry, to differentiate between the velocity of one of the occupant's hands, as in the case where he/she is adjusting the knob on the radio, and the remainder of the occupant. Three ultrasonic sensors of the type disclosed by White et al. might, in some cases, accomplish this differentiation if two of them indicated that the occupant was not moving while the third was indicating that he or she was moving. Such a combination, however, would not differentiate between an occupant with both hands and arms in the path of the ultrasonic transmitter at such a location that they were blocking a substantial view of the occupant's head or chest. Since the sizes and driving positions of occupants are extremely varied, trained pattern recognition systems, such as neural networks and combinations thereof, are required when a clear view of the occupant, unimpeded by his/her extremities, cannot be guaranteed. White et al. do not suggest the use of such neural networks.

Fujita et al., in U.S. Pat. No. 5,074,583, describe another method of determining the position of the occupant but do not use this information to control and suppress deployment of an airbag if the occupant is out-of-position, or if a rear facing child seat is present. In fact, the closer that the occupant gets to the airbag, the faster the inflation rate of the airbag is according to the Fujita et al. patent, which thereby increases the possibility of injuring the occupant. Fujita et al. do not measure the occupant directly but instead determine his or her position indirectly from measurements of the seat position and the vertical size of the occupant relative to the seat. This occupant height is determined using an ultrasonic displacement sensor mounted directly above the occupant's head.

It is important to note that in all cases in the above-cited prior art, except those assigned to the current assignee of the instant invention, no mention is made of the method of determining transducer location, deriving the algorithms or other system parameters that allow the system to accurately identify and locate an object in the vehicle. In contrast, in one implementation of the instant invention, the return ultrasonic echo pattern over several milliseconds corresponding to the entire portion of the passenger compartment volume of interest is analyzed from multiple transducers and sometimes combined with the output from other transducers, providing distance information to many points on the items occupying the passenger compartment.

Many of the teachings of this invention are based on pattern recognition technologies as taught in numerous textbooks and technical papers. Central to the diagnostic teachings of this invention are the manner in which the diagnostic module determines a normal pattern from an abnormal pattern and the manner in which it decides what data to use from the vast amount of data available. This is accomplished using pattern recognition technologies, such

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as artificial neural networks, including support vector machines, cellular neural networks and training. The theory of neural networks including many examples can be found in several books on the subject including. (1) *Techniques And Application Of Neural Networks*, edited by Taylor, M. and Lisboa, P., Ellis Horwood, West Sussex, England, 1993; (2) *Naturally Intelligent Systems*, by Caudill, M. and Butler, C., MIT Press, Cambridge, Mass., 1990; (3) J. M. Zaruda, *Introduction to Artificial Neural Systems*, West publishing Co., N.Y., 1992, (4) *Digital Neural Networks*, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, N.J., 1993, Eberhart, R., Simpson, P., (5) Dobbins, R., *Computational Intelligence PC Tools*, Academic Press, Inc., 1996, Orlando, Fla., (6) Cristianini, N. and Shawe-Taylor, J. *An Introduction to Support Vector Machines and other kernel-based learning methods*, Cambridge University Press, Cambridge England, 2000; (7) *Proceedings of the 2000 6<sup>th</sup> IEEE International Workshop on Cellular Neural Networks and their Applications (CNNA 2000)*, IEEE, Piscataway, N.J., and (8) Sinha, N. K. and Gupta, M. M. *Soft Computing & Intelligent Systems*, Academic Press 2000 San Diego, Calif., all of which are incorporated herein by reference. The neural network pattern recognition technology is one of the most developed of pattern recognition technologies. The invention described herein uses combinations of neural networks to improve the pattern recognition process.

Other patents describing occupant sensor systems include U.S. Pat. No. 5,482,314 (Corrado et al.) and U.S. Pat. No. 5,890,085 (Corrado et al.). These patents describe a system for sensing the presence, position and type of an occupant in a seat of a vehicle for use in enabling or disabling a related airbag activator. A preferred implementation of the system includes two or more different but collocated sensors which provide information about the occupant and this information is fused or combined in a microprocessor circuit to produce an output signal to the airbag controller. According to Corrado et al., the fusion process produces a decision as to whether to enable or disable the airbag with a higher reliability than a single phenomena sensor or non-fused multiple sensors. By fusing the information from the sensors to make a determination as to the deployment of the airbag, each sensor has only a partial effect on the ultimate deployment determination. The sensor fusion process is a crude pattern recognition process based on deriving the fusion "rules" by a trial and error process rather than by training.

The sensor fusion method of Corrado et al. requires that information from the sensors be combined prior to processing by an algorithm in the microprocessor. This combination could be found to unnecessarily complicate the processing of the data from the sensors and other data processing methods might provide better results. For example, as discussed more fully below, it has been found to be advantageous to use a more efficient pattern recognition algorithm such as a combination of neural networks or fuzzy logic algorithms which are arranged to receive a separate stream of data from each sensor, without that data being combined with data from the other sensors (as in done in Corrado et al.) prior to analysis by the pattern recognition algorithms. In this regard, it is critical to appreciate that sensor fusion is a form of pattern recognition but is not a neural network and that significant and fundamental differences exist between sensor fusion and neural networks. Thus, some embodiments of the invention described below differ from that of Corrado et al. because they include a microprocessor which is arranged to accept only a separate stream of data from each sensor such that the stream of data from the sensors are not combined with one another. Further, the microprocessor

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processes each separate stream of data independent of the processing of the other streams of data (i.e., without the use of any fusion matrix as in Corrado et al).

## 2. Definitions

The use of pattern recognition, or more particularly how it is used, is important to the instant invention. In the above-cited prior art, except in that assigned to the current assignee of the instant invention, pattern recognition which is based on training, as exemplified through the use of neural networks, is not mentioned for use in monitoring the interior passenger compartment or exterior environments of the vehicle. Thus, the methods used to adapt such systems to a vehicle are also not mentioned.

"Pattern recognition" as used herein will generally mean any system which processes a signal that is generated by an object (e.g., representative of a pattern of returned or received impulses, waves or other physical property specific to and/or characteristic of and/or representative of that object) or is modified by interacting with an object, in order to determine to which one of a set of classes that the object belongs. Such a system might determine only that the object is or is not a member of one specified class, or it might attempt to assign the object to one of a larger set of specified classes, or find that it is not a member of any of the classes in the set. The signals processed are generally a series of electrical signals coming from transducers that are sensitive to acoustic (ultrasonic) or electromagnetic radiation (e.g., visible light, infrared radiation, capacitance or electric and/or magnetic fields), although other sources of information are frequently included. Pattern recognition systems generally involve the creation of a set of rules that permit the pattern to be recognized. These rules can be created by fuzzy logic systems, statistical correlations, or through sensor fusion methodologies as well as by trained pattern recognition systems such as neural networks, combination neural networks, cellular neural networks or support vector machines.

A trainable or a trained pattern recognition system as used herein generally means a pattern recognition system which is taught to recognize various patterns constituted within the signals by subjecting the system to a variety of examples. The most successful such system is the neural network used either singly or as a combination of neural networks. Thus, to generate the pattern recognition algorithm, test data is first obtained which constitutes a plurality of sets of returned waves, or wave patterns, from an object (or from the space in which the object will be situated in the passenger compartment, i.e., the space above the seat) and an indication of the identify of that object. A number of different objects are tested to obtain the unique wave patterns from each object. As such, the algorithm is generated, and stored in a computer processor, and which can later be applied to provide the identity of an object based on the wave pattern being received during use by a receiver connected to the processor and other information. For the purposes here, the identity of an object sometimes applies to not only the object itself but also to its location and/or orientation in the passenger compartment. For example, a rear facing child seat is a different object than a forward facing child seat and an out-of-position adult can be a different object than a normally seated adult.

To "identify" as used herein will generally mean to determine that the object belongs to a particular set or class. The class may be one containing, for example, all rear facing child seats, one containing all human occupants, or all human occupants not sitting in a rear facing child seat depending on the purpose of the system. In the case where



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a particular person is to be recognized, the set or class will contain only a single element, i.e., the person to be recognized

An "object" in a vehicle or an "occupying item" of a seat may be a living occupant such as a human or a dog, another living organism such as a plant, or an inanimate object such as a box or bag of groceries or an empty child seat.

"Out-of-position" as used for an occupant will generally mean that the occupant, either the driver or a passenger is sufficiently close to the occupant protection apparatus (airbag) prior to deployment that he or she is likely to be more seriously injured by the deployment event itself than by the accident. It may also mean that the occupant is not positioned appropriately in order to attain beneficial, restraining effects of the deployment of the airbag. An occupant is too close to the airbag when the occupant's head or chest is closer than some distance, such as about 5 inches, from the deployment door of the airbag module. The actual distance value where airbag deployment should be suppressed depends on the design of the airbag module and is typically farther for the passenger airbag than for the driver airbag.

"Transducer" as used herein will generally mean the combination of a transmitter and a receiver. In some cases, the same device will serve both as the transmitter and receiver while in others two separate devices adjacent to each other will be used. In some cases, a transmitter is not used and in such cases transducer will mean only a receiver. Transducers include, for example, capacitive, inductive, ultrasonic, electromagnetic (antenna, CCD, CMOS arrays), weight measuring or sensing devices. In some cases, a transducer may comprise two parts such as the plates of a capacitor or the antennas of an electric field sensor. Sometimes, one antenna or plate will communicate with several other antennas or plates and thus for the purposes herein, a transducer will be broadly defined to refer, in most cases, to any one of the plates of a capacitor or antennas of a field sensor and in some other cases a pair of such plates or antennas will comprise a transducer as determined by the context in which the term is used.

"Adaptation" as used here will generally represent the method by which a particular occupant sensing system is designed and arranged for a particular vehicle model. It includes such things as the process by which the number, kind and location of various transducers is determined. For pattern recognition systems, it includes the process by which the pattern recognition system is designed and then taught or made to recognize the desired patterns. In this connection, it will usually include (1) the method of training when training is used, (2) the makeup of the databases used, testing and validating the particular system, or, in the case of a neural network, the particular network architecture chosen, (3) the process by which environmental influences are incorporated into the system, and (4) any process for determining the pre-processing of the data or the post processing of the results of the pattern recognition system. The above list is illustrative and not exhaustive. Basically, adaptation includes all of the steps that are undertaken to adapt transducers and other sources of information to a particular vehicle to create the system which accurately identifies and/or determines the location of an occupant or other object in a vehicle.

A "combination neural network" as used herein will generally apply to any combination of two or more networks that are either connected together or that analyze all or a portion of the input data. A combination neural network can be used to divide tasks in solving a particular occupant

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problem. For example, one neural network can be used to identify an object occupying a passenger compartment of an automobile and a second neural network can be used to determine the position of the object or its location with respect to the airbag, for example, within the passenger compartment. In another case, one neural network can be used merely to determine whether the data is similar to data upon which a main neural network has trained or whether there is something radically different about this data and therefore that the data should not be analyzed. Cellular neural networks are by nature combination neural networks as they involve at least two cellular networks. For the purposes herein, a neural network is defined to include all such learning systems including cellular neural networks, support vector machines and other kernel based learning systems and methods, cellular automata and all other pattern recognition methods and systems that learn. Combination neural networks are combinations of two or more such neural networks as most broadly defined.

With respect to a comparative analysis performed by neural networks to that performed by the human mind, once the human mind has identified that the object observed is a tree, the mind does not try to determine whether it is the black bear or a grizzly. Further observation on the tree might center on whether it is a pine tree, an oak tree etc. Thus the human mind appears to operate in some manner like a hierarchy of neural networks. Similarly, neural networks for analyzing the occupancy of the vehicle can be structured such that higher order networks are used to determine, for example, whether there is an occupying item of any kind present. This could be followed by the neural network that, knowing that there is information on the item, attempts to categorize the item into child seats and human adults etc., i.e., determine the type of item. Once it has decided that a child seat is present, then another neural network can be used to determine whether the child seat is rear facing or forward facing. Once the decision has been made that the child seat is facing rearward, the position of the child seat relative to the airbag, for example, can be handled by still another neural network. The overall accuracy of the system can be substantially improved by breaking the pattern recognition process down into a larger number of smaller pattern recognition problems.

In some cases, the accuracy of the pattern recognition process can be improved if the system uses data indicating its own recent decisions. Thus, for example, if the neural network system had determined that a forward facing adult was present, then that information can be used as input into another neural network, biasing any results toward the forward facing human compared to a rear facing child seat, for example. Similarly, for the case when an occupant is being tracked in his or her forward motion during a crash, for example, the location of the occupant at the previous calculation time step can be valuable information to determining the location of the occupant from the current data. There is a limited distance an occupant can move in 10 milliseconds, for example. In this latter example, feedback of the decision of the neural network tracking algorithm becomes important input into the same algorithm for the calculation of the position of the occupant at the next time step.

What has been described above is generally referred to as modular neural networks with and without feedback. Actually, the feedback does not have to be from the output to the input of the same neural network. The feedback from a downstream neural network could be input to an upstream neural network, for example.

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The neural networks can be combined in other ways, for example in a voting situation. Sometimes the data upon which the system is trained is sufficiently complex or imprecise that different views of the data will give different results. For example, a subset of transducers may be used to train one neural network and another subset to train a second neural network etc. The decision can then be based on a voting of the parallel neural networks, known as an ensemble neural networks. In the past, neural networks have usually only been used in the form of a single neural network algorithm for identifying the occupancy state of an automobile. This invention is primarily advancing the state of the art and using combination neural networks wherein two or more neural networks are combined to arrive at a decision. Cellular neural networks, for example, are by nature combination neural networks.

In the description herein on anticipatory sensing, the term "approaching" when used in connection with the mention of an object or vehicle approaching another will generally mean the relative motion of the object toward the vehicle having the anticipatory sensor system. Thus, in a side impact with a tree, the tree will be considered as approaching the side of the vehicle and impacting the vehicle. In other words, the coordinate system used in general will be a coordinate system residing in the target vehicle. The "target" vehicle is the vehicle which is being impacted. This convention permits a general description to cover all of the cases such as where (i) a moving vehicle impacts into the side of a stationary vehicle, (ii) where both vehicles are moving when they impact, or (iii) where a vehicle is moving sideways into a stationary vehicle, tree or wall. Also, for the purposes herein, a "wave sensor" or "wave transducer" is generally any device, which senses either ultrasonic or electromagnetic waves. An electromagnetic wave sensor, for example, includes devices that sense any portion of the electromagnetic spectrum from ultraviolet down to a few hertz. The most commonly used kinds of electromagnetic wave sensors include CCD and CMOS arrays for sensing visible and/or infrared waves, millimeter wave and microwave radar, and capacitive or electric and/or magnetic field monitoring sensors that rely on the dielectric constant of the object occupying a space but also rely on the time variation of the field, expressed by waves as defined below, to determine a change in state. In this regard, reference is made to, for example, U.S. patents by Kithil et al. U.S. Pat. Nos. 5,366,241, 5,602,734, 5,691,693, 5,802,479 and 5,844,486 and Jinno et al. U.S. Pat. No. 5,948,031 which are incorporated herein by reference.

Electric and magnetic field sensors and wave sensors are essentially the same from the point of view of sensing the presence of an occupant in a vehicle. In both cases, a time varying electric and/or magnetic field is disturbed or modified by the presence of the occupant. At high frequencies in the visual, infrared and high frequency radio wave region, the sensor is based on the reflection of electromagnetic energy. As the frequency drops and more of the energy passes through the occupant, the absorption of the wave energy is measured and at still lower frequencies the occupant's dielectric and displacement current properties modify the standing wave in the occupied space between the plates of a capacitor. In this latter case, the sensor senses the change in charge distribution on the capacitor plates by measuring, for example, the current wave magnitude or phase in the electric circuit that drives the capacitor. In all cases, the presence of the occupant reflects, absorbs or modifies the waves or variations in the electric or magnetic field (standing waves) in the space occupied by the occu-

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pant. Thus, for the purposes of this invention, capacitance, electric field and magnetic field sensors are equivalent and will be considered as wave sensors. What follows is a discussion comparing the similarities and differences between two types of wave sensors, electromagnetic beam sensors and capacitive sensors as exemplified by Kithil in U.S. Pat. No. 5,702,634 which is incorporated herein by reference.

An electromagnetic field disturbed or emitted by a passenger in the case of an electromagnetic beam sensor, for example, and the electric field sensor of Kithil, for example, are in many ways similar and equivalent for the purposes of this invention. The electromagnetic beam sensor is an actual electromagnetic wave sensor by definition, which is a coupled pair of continuously changing electric and magnetic fields. The electric field here is not a static, potential one. It is essentially a dynamic, vortex electric field coupled with a changing magnetic one, that is, an electromagnetic wave. It cannot be produced by a steady distribution of electric charges. It is initially produced by moving electric charges in a transmitter, even if this transmitter is a passenger body for the case of a passive infrared sensor.

In the Kithil sensor, a static electric field is declared as an initial material agent coupling a passenger and a sensor (see column 5, lines 5-7): "The proximity sensor 12 each function by creating an electrostatic field between oscillator input loop 54 and detector output loop 56, which is affected by presence of a person near by, as a result of capacitive coupling, . . . "). It is a potential, non-vortex electric field. It is not necessarily coupled with any magnetic field. It is the electric field of a capacitor. It can be produced with a steady distribution of electric charges. Thus, it is not an electromagnetic wave by definition but if the sensor is driven by a varying current then it produces standing electric waves in the space between the plates of the capacitor.

Kithil declares that he uses a static electric field in his capacitance sensor. Thus, from the consideration above, one can conclude that Kithil's sensor cannot be treated as a wave sensor because there are no actual electromagnetic, or electric, waves but only a static electric field of the capacitor in the sensor system. However this is not the case. The Kithil system could not operate with a true static electric field because a steady system does not carry any information. Therefore, Kithil is forced to use an oscillator, causing an alternate current in the capacitor and a standing electric wave in the space between the capacitor plates, and a detector to reveal an informative change of the sensor capacitance caused by the presence of an occupant (see FIG. 7 and its description). In this case, his system becomes a wave sensor in the sense that it starts generating actual electric waves according to the definition above. That is, Kithil's sensor can be treated as a wave sensor regardless of the shape of the electric field that it creates, a beam or a spread shape.

As described in the Kithil patents, the capacitor sensor is a parametric system where the capacitance of the sensor is controlled by influence of the passenger body. This influence is transferred by means of the electromagnetic field (i.e., the wave process) coupling the capacitor electrodes and the body. It is important to note, that the same influence takes place with a static electric field also, that is in absence of any wave phenomenon. This would be a situation if there were no oscillator in Kithil's system. However, such a system is not workable and thus Kithil reverts to a dynamic system using electric waves.

Thus, although Kithil declares the coupling is due to a static electric field, such a situation is not realized in his

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system because an alternating electromagnetic field (“wave”) exists in the system due to the oscillator. Thus, his sensor is actually a wave sensor, that is, it is sensitive to a change of a wave field in the vehicle compartment. This change is measured by measuring the change of its capacitance. The capacitance of the sensor system is determined by the configuration of its electrodes, one of which is a human body, that is, the passenger inside of and the part which controls the electrode configuration and hence a sensor parameter, the capacitance.

The physics definition of “wave” from Webster’s Encyclopedic Unabridged Dictionary is: “11. Physics. A progressive disturbance propagated from point to point in a medium or space without progress or advance of the points themselves, . . .”. In a capacitor, the time that it takes for the disturbance (a change in voltage) to propagate through space, the dielectric and to the opposite plate is generally small and neglected but it is not zero. As the frequency driving the capacitor increases and the distance separating the plates increases and this transmission time as a percentage of the period of oscillation can become significant. Nevertheless, an observer between the plates will see the rise and fall of the electric field much like a person standing in the water of an ocean. The presence of a dielectric body between the plates causes the waves to get bigger as more electrons flow to and from the plates of the capacitor. Thus, an occupant effects the magnitude of these waves which is sensed by the capacitor circuit. Thus, the electromagnetic field is a material agent that carries information about a passenger’s position in both Kithil’s and a beam type electromagnetic wave sensor.

The following definitions are from the Encyclopedia Britannica:

#### Electromagnetic Field

“A property of space caused by the motion of an electric charge. A stationary charge will produce only an electric field in the surrounding space. If the charge is moving, a magnetic field is also produced. An electric field can be produced also by a changing magnetic field. The mutual interaction of electric and magnetic fields produces an electromagnetic field, which is considered as having its own existence in space apart from the charges or currents (a stream of moving charges) with which it may be related . . . .” (Copyright 1994–1998 Encyclopedia Britannica)

#### Displacement Current

“ . . . in electromagnetism, a phenomenon analogous to an ordinary electric current, posited to explain magnetic fields that are produced by changing electric fields. Ordinary electric currents, called conduction currents, whether steady or varying, produce an accompanying magnetic field in the vicinity of the current. [ . . . ]

“As electric charges do not flow through the insulation from one plate of a capacitor to the other, there is no conduction current; instead, a displacement current is said to be present to account for the continuity of the magnetic effects. In fact, the calculated size of the displacement current between the plates of a capacitor being charged and discharged in an alternating-current circuit is equal to the size of the conduction current in the wires leading to and from the capacitor. Displacement currents play a central role in the propagation of electromagnetic radiation, such as light and radio waves, through empty space. A traveling, varying magnetic field is everywhere associated with a periodically changing electric field that may be conceived in terms of a displacement current. Maxwell’s insight on displacement current, therefore, made it possible to understand electro-

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magnetic waves as being propagated through space completely detached from electric currents in conductors.” Copyright 1994–1998 Encyclopedia Britannica.

#### Electromagnetic Radiation

“ . . . energy that is propagated through free space or through a material medium in the form of electromagnetic waves, such as radio waves, visible light, and gamma rays. The term also refers to the emission and transmission of such radiant energy [ . . . ]

“It has been established that time-varying electric fields can induce magnetic fields and that time-varying magnetic fields can in like manner induce electric fields. Because such electric and magnetic fields generate each other, they occur jointly, and together they propagate as electromagnetic waves. An electromagnetic wave is a transverse wave in that the electric field and the magnetic field at any point and time in the wave are perpendicular to each other as well as to the direction of propagation. [ . . . ]

“Electromagnetic radiation has properties in common with other forms of waves such as reflection, refraction, diffraction, and interference. [ . . . ]” Copyright 1994–1998 Encyclopedia Britannica.

The main part of the Kithil “circuit means” is an oscillator, which is as necessary in the system as the capacitor itself to make the capacitive coupling effect be detectable. An oscillator by nature creates waves. The system can operate as a sensor only if an alternating current flows through the sensor capacitor, which, in fact, is a detector from which an informative signal is acquired. Then this current (or, more exactly, integral of the current over time—charge) is measured and the result is a measure of the sensor capacitance value. The latter in turn depends on the passenger presence that affects the magnitude of the waves that travel between the plates of the capacitor making the Kithil sensor a wave sensor by the definition herein.

An additional relevant definitions is:

#### Capacitive Coupling

The transfer of energy from one circuit to another by means of the mutual capacitance between the circuits. (188) Note 1: The coupling may be deliberate or inadvertent. Note 2: Capacitive coupling favors transfer of the higher frequency components of a signal, whereas inductive coupling favors lower frequency components, and conductive coupling favors neither higher nor lower frequency components.”

Another similarity between one embodiment of the sensor of this invention and the Kithil sensor is the use of a voltage-controlled oscillator (VCO).

#### 3. Pattern Recognition Prior Art

Japanese Patent No. 3-42337 (A) to Ueno describes a device for detecting the driving condition of a vehicle driver comprising a light emitter for irradiating the face of the driver and a means for picking up the image of the driver and storing it for later analysis. Means are provided for locating the eyes of the driver and then the irises of the eyes and then determining if the driver is looking to the side or sleeping. Ueno determines the state of the eyes of the occupant rather than determining the location of the eyes relative to the other parts of the vehicle passenger compartment. Such a system can be defeated if the driver is wearing glasses, particularly sunglasses, or another optical device which obstructs a clear view of his/her eyes. Neural networks are not used. The method of finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,008,946 to Ando uses a complicated set of rules to isolate the eyes and mouth of a driver and uses this information to permit the driver to control the radio, for



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example, or other systems within the vehicle by moving his eyes and/or mouth. Ando uses visible light and illuminates only the head of the driver. He also makes no use of trainable pattern recognition systems such as neural networks, nor is there any attempt to identify the contents of the vehicle nor of their location relative to the vehicle passenger compartment. Rather, Ando is limited to control of vehicle devices by responding to motion of the driver's mouth and eyes. As with Ueno, a method of finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,298,732, filed Feb. 18, 1993, to Chen also concentrates on locating the eyes of the driver so as to position a light filter between a light source such as the sun or the lights of an oncoming vehicle, and the driver's eyes. Chen does not explain in detail how the eyes are located but does supply a calibration system whereby the driver can adjust the filter so that it is at the proper position relative to his or her eyes. Chen references the use of an automatic equipment for determining the location of the eyes but does not describe how this equipment works. In any event, in Chen, there is no mention of monitoring the position of the occupant, other than the eyes, determining the position of the eyes relative to the passenger compartment, or identifying any other object in the vehicle other than the driver's eyes. Also, there is no mention of the use of a trainable pattern recognition system. A method for finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,305,012 to Faris also describes a system for reducing the glare from the headlights of an oncoming vehicle. Faris locates the eyes of the occupant by using two spaced apart infrared cameras using passive infrared radiation from the eyes of the driver. Faris is only interested in locating the driver's eyes relative to the sun or oncoming headlights and does not identify or monitor the occupant or locate the occupant, a rear facing child seat or any other object for that matter, relative to the passenger compartment or the airbag. Also, Faris does not use trainable pattern recognition techniques such as neural networks. Faris, in fact, does not even say how the eyes of the occupant are located but refers the reader to a book entitled Robot Vision (1991) by Berthold Horn, published by MIT Press, Cambridge, Mass. Also, Faris uses the passive infrared radiation rather than illuminating the occupant with ultrasonic or electromagnetic radiation as in some implementations of the instant invention. A method for finding the eyes of the occupant is described but not a method of adapting the system to a particular vehicle model.

The use of neural networks, or neural fuzzy systems, and in particular combination neural networks, as the pattern recognition technology and the methods of adapting this to a particular vehicle, such as the training methods, is important to this invention since it makes the monitoring system robust, reliable and accurate. The resulting systems are easy to implement at a low cost making them practical for automotive applications. The cost of the ultrasonic transducers, for example, is expected to be less than about \$1 in quantities of one million per year and CMOS cameras, currently less than \$5 each in similar quantities. Similarly, the implementation of the techniques of the above-referenced patents requires expensive microprocessors while the implementation with neural networks and similar trainable pattern recognition technologies permits the use of low cost microprocessors typically costing less than about \$5 in quantities of one million per year.

The present invention is best implemented using sophisticated software that develops trainable pattern recognition

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algorithms such as neural networks and combination neural networks. Usually the data is preprocessed, as discussed below, using various feature extraction techniques and the results post-processed to improve system accuracy. A non-automotive example of such a pattern recognition system using neural networks on sonar signals is discussed in two papers by Gorman, R. P. and Sejnowski, T. J. "Analysis of Hidden Units in a Layered Network Trained to Classify Sonar Targets", Neural Networks, Vol. 1. pp. 75-89, 1988, and "Learned Classification of Sonar Targets Using a Massively Parallel Network", IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol. 36, No. 7, July 1988. Examples of feature extraction techniques can be found in U.S. Pat. No. 4,906,940 entitled "Process and Apparatus for the Automatic Detection and Extraction of Features in Images and Displays" to Green et al. Examples of other more advanced and efficient pattern recognition techniques can be found in U.S. Pat. No. 5,390,136 entitled "Artificial Neuron and Method of Using Same" and U.S. Pat. No. 5,517,667 entitled "Neural Network That Does Not Require Repetitive Training" to Wang, S. T. Other examples include U.S. Pat. No. 5,235,339 (Morrison et al.), U.S. Pat. No. 5,214,744 (Schweizer et al), U.S. Pat. No. 5,181,254 (Schweizer et al), and U.S. Pat. No. 4,881,270 (Knecht et al) All of the references herein are incorporated herein by reference.

#### 4. Ultrasonics and Optics

Both laser and non-laser optical systems in general are good at determining the location of objects within the two dimensional plane of the image and a pulsed laser radar system in the scanning mode can determine the distance of each part of the image from the receiver by measuring the time of flight through range gating techniques. Distance can also be determined by using modulated electromagnetic radiation and measuring the phase difference between the transmitted and received waves. It is also possible to determine distance with the non-laser system by focusing, or stereographically if two spaced apart receivers are used and, in some cases, the mere location in the field of view can be used to estimate the position relative to the airbag, for example. Finally, a recently developed pulsed quantum well diode laser also provides inexpensive distance measurements as discussed in U.S. Pat. No. 6,324,453, which is incorporated herein by reference as if the entire contents were copied here.

Acoustic systems are additionally quite effective at distance measurements since the relatively low speed of sound permits simple electronic circuits to be designed and minimal microprocessor capability is required. If a coordinate system is used where the z-axis is from the transducer to the occupant, acoustics are good at measuring z dimensions while simple optical systems using a single CCD or CMOS arrays are good at measuring x and y dimensions. The combination of acoustics and optics, therefore, permits all three measurements to be made from one location with low cost components as discussed in commonly assigned U.S. Pat. Nos. 5,845,000 and 5,835,613 cross-referenced above.

One example of a system using these ideas is an optical system which floods the passenger seat with infrared light coupled with a lens and a receiver array, e.g., CCD or CMOS array, which receives and displays the reflected light and an analog to digital converter (ADC) which digitizes the output of the CCD or CMOS and feeds it to an Artificial Neural Network (ANN) or other pattern recognition system for analysis. This system uses an ultrasonic transmitter and receiver for measuring the distances to the objects located in the passenger seat. The receiving transducer feeds its data



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into an ADC and from there the converted data is directed into the ANN. The same ANN can be used for both systems thereby providing full three-dimensional data for the ANN to analyze. This system, using low cost components, will permit accurate identification and distance measurements not possible by either system acting alone. If a phased array system is added to the acoustic part of the system, the optical part can determine the location of the driver's ears, for example, and the phased array can direct a narrow beam to the location and determine the distance to the occupant's ears.

Although the use of ultrasound for distance measurement has many advantages, it also has some drawbacks. First, the speed of sound limits the rate at which the position of the occupant can be updated to approximately 10 milliseconds, which though sufficient for most cases, is marginal if the position of the occupant is to be tracked during a vehicle crash. Second, ultrasound waves are diffracted by changes in air density that can occur when the heater or air conditioner is operated or when there is a high-speed flow of air past the transducer. Third, the resolution of ultrasound is limited by its wavelength and by the transducers, which are high Q tuned devices. Typically, the resolution of ultrasound is on the order of about 2 to 3 inches. Finally, the fields from ultrasonic transducers are difficult to control so that reflections from unwanted objects or surfaces add noise to the data.

Ultrasonics alone can be used in several configurations for monitoring the interior of a passenger compartment of an automobile as described in the above-referenced patents and patent applications and in particular in U.S. Pat. No. 5,943,295 Using the teachings of this invention, the optimum number and location of the ultrasonic and/or optical transducers can be determined as part of the adaptation process for a particular vehicle model.

In the cases of the instant invention, as discussed in more detail below, regardless of the number of transducers used, a trained pattern recognition system, as defined above, is preferably used to identify and classify, and in some cases to locate, the illuminated object and its constituent parts.

#### 5. Applications

The applications for this technology are numerous as described in the patents and patent applications listed above. However, the main focus of the instant invention is the process and resulting apparatus of adapting the system in the patents and patent applications referenced above and using combination neural networks for the detection of the presence of an occupied child seat in the rear facing position or an out-of-position occupant and the detection of an occupant in a normal seating position. The system is designed so that in the former two cases, deployment of the occupant protection apparatus (airbag) may be controlled and possibly suppressed, and in the latter case, it will be controlled and enabled.

One preferred implementation of a first generation occupant sensing system, which is adapted to various vehicle models using the teachings presented herein, is an ultrasonic occupant position sensor. This system uses a Combination Artificial Neural Network (CANN) to recognize patterns that it has been trained to identify as either airbag enable or airbag disable conditions. The pattern is obtained from four ultrasonic transducers that cover the front passenger seating area. This pattern consists of the ultrasonic echoes bouncing off of the objects in the passenger seat area. The signal from each of the four transducers consists of the electrical image of the return echoes, which is processed by the electronics. The electronic processing comprises amplification, logarithmic compression, rectification, and demodulation (band pass

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filtering), followed by discretization (sampling) and digitization of the signal. The only software processing required, before this signal can be fed into the combination artificial neural network, is normalization (i.e., mapping the input to numbers between 0 and 1). Although this is a fair amount of processing, the resulting signal is still considered "raw", because all information is treated equally.

#### OBJECTS AND SUMMARY OF THE INVENTION

In general, it is an object of the present invention to provide a new and improved system for identifying the presence, position and/or orientation of an object in a vehicle.

It is another broad object of the present invention to provide a system for accurately detecting the presence of an occupied rear-facing child seat in order to prevent an occupant protection apparatus, such as an airbag, from deploying, when the airbag would impact against the rear-facing child seat if deployed.

It is yet another broad object of the present invention to provide a system for accurately detecting the presence of an out-of-position occupant in order to prevent one or more deployable occupant protection apparatus such as airbags from deploying when the airbag(s) would impact against the head or chest of the occupant during its initial deployment phase causing injury or possible death to the occupant.

This invention is a system designed to identify, locate and monitor occupants, including their parts, and other objects in the passenger compartment and in particular an occupied child seat in the rear facing position or an out-of-position occupant, by illuminating the contents of the vehicle with ultrasonic or electromagnetic radiation, for example, by transmitting radiation waves, as broadly defined above to include capacitors and electric or magnetic fields, from a wave generating apparatus into a space above the seat, and receiving radiation modified by passing through the space above the seat using two or more transducers properly located in the vehicle passenger compartment, in specific predetermined optimum locations. More particularly, this invention relates to a system including a plurality of transducers appropriately located and mounted and which analyze the received radiation from any object which modifies the waves or fields, or which analyze a change in the received radiation caused by the presence of the object (e.g., a change in the dielectric constant), in order to achieve an accuracy of recognition heretofore not possible. Outputs from the receivers are analyzed by appropriate computational means employing trained pattern recognition technologies, and in particular combination neural networks, to classify, identify and/or locate the contents, and/or determine the orientation of, for example, a rear facing child seat. In general, the information obtained by the identification and monitoring system is used to affect the operation of some other system, component or device in the vehicle and particularly the passenger and/or driver airbag systems, which may include a front airbag, a side airbag, a knee bolster, or combinations of the same. However, the information obtained can be used for controlling or affecting the operation of a multitude of other vehicle systems.

When the vehicle interior monitoring system in accordance with the invention is installed in the passenger compartment of an automotive vehicle equipped with a occupant protection apparatus, such as an inflatable airbag, and the vehicle is subjected to a crash of sufficient severity that the crash sensor has determined that the protection apparatus is

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to be deployed, the system has determined (usually prior to the deployment) whether a child placed in the child seat in the rear facing position is present and if so, a signal has been sent to the control circuitry that the airbag should be controlled and most likely disabled and not deployed in the crash. It must be understood though that instead of suppressing deployment, it is possible that the deployment may be controlled so that it might provide some meaningful protection for the occupied rear-facing child seat. The system developed using the teachings of this invention also determines the position of the vehicle occupant relative to the airbag and controls and possibly disables deployment of the airbag if the occupant is positioned so that he/she is likely to be injured by the deployment of the airbag. As before, the deployment is not necessarily disabled but may be controlled to provide protection for the out-of-position occupant

Principle objects and advantages of the methods in accordance with the invention are:

1. To provide a reliable system for recognizing the presence of a rear-facing child seat on a particular seat of a motor vehicle.
2. To provide a reliable system for recognizing the presence of a human being on a particular seat of a motor vehicle.
3. To provide a reliable system for determining the position, velocity or size of an occupant in a motor vehicle.
4. To provide a reliable system for determining in a timely manner that an occupant is out-of-position, or will become out-of-position, and likely to be injured by a deploying airbag.
5. To provide a system in which transducers are located within the passenger compartment at specific locations such that a high reliability of classification of objects and their position is obtained from the signals generated by the transducers.
6. To provide a system including a variety of transducers such as seatbelt payout sensors, seatbelt buckle sensors, seat position sensors, seatback position sensors, and weight sensors and which is adapted so as to constitute a highly reliable occupant presence and position system when used in combination with electromagnetic, ultrasonic or other radiation or field sensors.

Accordingly, a method for controlling an occupant protection device in a vehicle comprises the steps of acquiring data from at least one sensor relating to an occupant in a seat to be protected by the occupant protection device, classifying the type of occupant based on the acquired data, when the occupant is classified as an empty seat or a rear-facing child seat, disabling or adjusting deployment of the occupant protection device, otherwise classifying the size of the occupant based on the acquired data, determining the position of the occupant by means of one of a plurality of algorithms selected based on the classified size of the occupant using the acquired data, each of the algorithms being applicable for a specific size of occupant, and disabling or adjusting deployment of the occupant protection device when the determined position of the occupant is more likely to result in injury to the occupant if the occupant protection device were to deploy. The algorithms may be pattern recognition algorithms such as neural networks.

Acquisition of data may be from a plurality of sensors arranged in the vehicle, each providing data relating to the occupancy state of the seat. Possible sensors include a camera, an ultrasonic sensor, a capacitive sensor or other

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electromagnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor. Further sensors include an electromagnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, and a heartbeat sensor for sensing a heartbeat of the occupant.

Classification of the type of occupant and the size of the occupant may be performed by a combination neural network created from a plurality of data sets, each data set representing a different occupancy state of the seat and being formed from data from the at least one sensor while the seat is in that occupancy state.

A feedback loop may be used in which a previous determination of the position of the occupant is provided to the algorithm for determining a current position of the occupant.

Adjustment of deployment of the occupant protection device when the occupant is classified as an empty seat or a rear-facing child seat may entail a depowered deployment, an oriented deployment and/or a late deployment.

A gating function may be incorporated into the method whereby it is determined whether the acquired data is compatible with data for classification of the type or size of the occupant and when the acquired data is not compatible with the data for classification of the type or size of the occupant, the acquired data is rejected and new data is acquired.

Another method for controlling a component in a vehicle entails acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, determining an occupancy state of the seat based on the acquired data, periodically acquiring new data from the at least one sensor, for each time new data is acquired, determining the occupancy state of the seat based on the acquired new data and the determined occupancy state from a preceding time and controlling the component based on the determined occupancy state of the seat. This thus involves use of a feedback loop.

The determination of the occupancy state of the seat is performed using at least one pattern recognition algorithm such as a combination neural network.

Another method for controlling a component in a vehicle comprises the steps of acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, identifying the occupant based on the acquired data, determining the position of the occupant based on the acquired data, controlling the component based on at least one of the identification of the occupant and the determined position of the occupant, periodically acquiring new data from the at least one sensor, and for each time new data is acquired, identifying the occupant based on the acquired new data and an identification from a preceding time and determining the position of the occupant based on the acquired new data and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant. This also involves use of a feedback loop.

Determination of the position of the occupant based on the acquired new data may entail considering a determination of the position of the occupant from the preceding time.

Identification of the occupant based on the acquired data may entail using data from a first subset of the plurality of sensors whereas the determination of the position of the

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occupant based on the acquired data may entail using data from a second subset of the plurality of sensors different than the first subset.

Identification of the occupant based on the acquired data and the determination of the position of the occupant based on the acquired data may be performed using pattern recognition algorithms such as a combination neural network.

Another method for controlling a component in a vehicle may comprise the steps of acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, identifying an occupant based on the acquired data, determining the position of the occupant based on the acquired data, controlling the component based on at least one of the identification of the occupant and the determined position of the occupant, periodically acquiring new data from the at least one sensor, and for each time new data is acquired, identifying an occupant based on the acquired new data and determining the position of the occupant based on the acquired new data and a determination of the position of the occupant from a preceding time and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant.

Another method for controlling a component in a vehicle comprises the steps of acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component, identifying the occupant based on the acquired data, when the occupant is identified as a child seat, determining the orientation of the child seat based on the acquired data, determining the position of the child seat by means of one of a plurality of algorithms selected based on the determined orientation of the child seat, each of the algorithms being applicable for a specific orientation of a child seat, and controlling the component based on the determined position of the child seat. When the occupant is identified as other than a child seat, the method entails determining at least one of the size and position of the occupant and controlling the component based on the at least one of the size and position of the occupant.

In some of the implementations of the invention described above, a combination or combinational neural network is used. The particular combination neural network can be determined by a process in which a number of neural network modules are combined in a parallel and a serial manner and an optimization program can be utilized to determine the best combination of such neural networks to achieve the highest accuracy. Alternately, the optimization process can be undertaken manually in a trial and error manner. In this manner, the optimum combination of neural networks is selected to solve the particular pattern recognition and categorization objective desired.

These and other objects and advantages will become apparent from the following description of the preferred embodiments of the vehicle identification and monitoring system of this invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings are illustrative of embodiments of the system developed or adapted using the teachings of this invention and are not meant to limit the scope of the invention as encompassed by the claims. In particular, the illustrations below are limited to the monitoring of the front passenger seat for the purpose of describing the system. Naturally, the invention applies as well to adapting the system to the other seating positions in the vehicle and particularly to the driver position.

FIG. 1 shows a seated-state detecting unit developed in accordance with the present invention and the connections

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between ultrasonic or electromagnetic sensors including wave and field sensors, a weight sensor, a reclining angle detecting sensor, a seat track position detecting sensor, a heartbeat sensor, a motion sensor, a neural network circuit, and an airbag system installed within a vehicle compartment;

FIG. 2 is a perspective view of a vehicle containing two adult occupants on the front seat with the vehicle shown in phantom illustrating one preferred location of the transducers placed according to the methods taught in this invention.

FIG. 3 is a view as in FIG. 2 with the passenger occupant replaced by a child in a forward facing child seat.

FIG. 4 is a view as in FIG. 2 with the passenger occupant replaced by a child in a rearward facing child seat.

FIG. 5 is a view as in FIG. 2 with the passenger occupant replaced by an infant in an infant seat.

FIG. 6 is a diagram illustrating the interaction of two ultrasonic sensors and how this interaction is used to locate a circle in space.

FIG. 7 is a view as in FIG. 2 with the occupants removed illustrating the location of two circles in space and how they intersect the volumes characteristic of a rear facing child seat and a larger occupant.

FIG. 8 illustrates a preferred mounting location of a three-transducer system.

FIG. 9 illustrates a preferred mounting location of a four-transducer system.

FIG. 10 is a plot showing the target volume discrimination for two transducers.

FIG. 11 illustrates a preferred mounting location of a eight-transducer system.

FIG. 12 is a schematic illustrating a combination neural network system.

FIG. 13 is a schematic illustration of a method in which the occupancy state of a seat of a vehicle is determined using a combination neural network in accordance with the invention.

FIG. 14 is a schematic illustration of a method in which the identification and position of the occupant is determined using a combination neural network in accordance with the invention.

FIG. 15 is a schematic illustration of a method in which the occupancy state of a seat of a vehicle is determined using a combination neural network in accordance with the invention in which bad data is prevented from being used to determine the occupancy state of the vehicle.

FIG. 16 is a schematic illustration of another method in which the occupancy state of a seat of a vehicle is determined, in particular, for the case when a child seat is present, using a combination neural network in accordance with the invention.

FIG. 17 is a schematic illustration of a method in which the occupancy state of a seat of a vehicle is determined using a combination neural network in accordance with the invention, in particular, an ensemble arrangement of neural networks.

FIG. 18 is a database of data sets for use in training of a neural network in accordance with the invention.

FIG. 19 is a categorization chart for use in a training set collection matrix in accordance with the invention.

FIGS. 20, 21 and 22 are charts of infant seats, child seats and booster seats showing attributes of the seats and a designation of their use in the training database, validation database or independent database in and exemplifying embodiment of the invention.



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FIGS. 23A–23D show a chart showing different vehicle configurations for use in training of combination neural network in accordance with the invention.

FIGS. 24A–24H show a training set collection matrix for training a neural network in accordance with the invention.

FIG. 25 shows an independent test set collection matrix for testing a neural network in accordance with the invention.

FIG. 26 is a table of characteristics of the data sets used in the invention.

FIG. 27 is a table of the distribution of the main training subjects of the training data set.

FIG. 28 is a table of the distribution of the types of child seats in the training data set.

FIG. 29 is a table of the distribution of environmental conditions in the training data set.

FIG. 30 is a table of the distribution of the validation data set.

FIG. 31 is a table of the distribution of human subjects in the validation data set.

FIG. 32 is a table of the distribution of child seats in the validation data set.

FIG. 33 is a table of the distribution of environmental conditions in the validation data set.

FIG. 34 is a table of the inputs from ultrasonic transducers.

FIG. 35 is a table of the baseline network performance.

FIG. 36 is a table of the performance per occupancy subset.

FIG. 37 is a table of the performance per environmental conditions subset.

FIG. 38 is a chart of four typical raw signals which are combined to constitute a vector.

FIG. 39 is a table of the results of the normalization study.

FIG. 40 is a table of the results of the low threshold filter study.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

System Adaptation involves the process by which the hardware configuration and the software algorithms are determined for a particular vehicle. Each vehicle model or platform will most likely have a different hardware configuration and different algorithms. Some of the various aspects that make up this process are as follows:

The determination of the mounting location and aiming or orientation of the transducers.

The determination of the transducer field angles or area or volume monitored

The use of a combination neural network algorithm generating program such as available from International Scientific Research, Inc. to help generate the algorithms or other pattern recognition algorithm generation program.

The process of the collection of data in the vehicle, for example, for neural network training purposes.

The method of automatic movement of the vehicle seats etc. while data is collected

The determination of the quantity of data to acquire and the setups needed to achieve a high system accuracy, typically several hundred thousand vectors or data sets.

The collection of data in the presence of varying environmental conditions such as with thermal gradients.

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The photographing of each data setup.

The makeup of the different databases and the use of typically three different databases.

The method by which the data is biased to give higher probabilities for forward facing humans.

The automatic recording of the vehicle setup including seat, seat back, headrest, window, visor, armrest etc. positions to help insure data integrity.

The use of a daily setup to validate that the transducer configuration and calibration has not changed.

The method by which bad data is culled from the database.

The inclusion of the Fourier transforms and other pre-processors of the data in the algorithm generation process.

The use of multiple algorithm levels, for example, for categorization and position.

The use of multiple algorithms in parallel.

The use of post processing filters and the particularities of these filters.

The addition of fuzzy logic or other human intelligence based rules.

The method by which data errors are corrected using, for example, a neural network.

The use of a neural network generation program as the pattern recognition algorithm generating system.

The use of back propagation neural networks from training.

The use of vector or data normalization.

The use of feature extraction techniques, for ultrasonic systems for example, including:

The number of data points prior to a peak.

The normalization factor.

The total number of peaks.

The vector or data set mean or variance.

The use of feature extraction techniques, for optics systems for example, including:

Motion.

Edge detection.

Feature detection such as the eyes, head etc.

Texture detection.

Recognizing specific features of the vehicle.

Line subtraction—i.e. subtracting one line of pixels from the adjacent line.

The use of other computational intelligence systems such as the genetic algorithms

The use the data screening techniques.

The techniques used to develop a stable networks including the concepts of old and new networks.

The time spent or the number of iterations spent in, and method of, arriving at stable networks.

The technique where a small amount of data is collected first such as 16 sheets followed by a complete data collection sequence.

The use of a cellular neural network for high speed data collection and analysis when electromagnetic transducers are used.

The use of a support vector machine.

The process of adapting the system to the vehicle begins with a survey of the vehicle model. Any existing sensors, such as seat position sensors, seat back sensors, etc., are immediate candidates for inclusion into the system Input from the customer will determine what types of sensors

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would be acceptable for the final system. These sensors can include: seat structure mounted weight sensors, pad type weight sensors, pressure type weight sensors (e.g. bladders), seat fore and aft position sensors, seat-mounted capacitance, electric field or antenna sensors, seat vertical position sensors, seat angular position sensors, seat back position sensors, headrest position sensors, ultrasonic occupant sensors, optical occupant sensors, capacitive sensors, electric field sensors, inductive sensors, radar sensors, vehicle velocity and acceleration sensors, brake pressure, seatbelt force, payout and buckle sensors, accelerometers, gyroscopes, chemical etc. A candidate array of sensors is then chosen and mounted onto the vehicle.

The vehicle is also instrumented so that data input by humans is minimized. Thus, the positions of the various components in the vehicle such as the seats, windows, sun visor, armrest, etc. are automatically recorded where possible. Also, the position of the occupant while data is being taken is also recorded through a variety of techniques such as direct ultrasonic ranging sensors, optical ranging sensors, radar ranging sensors, optical tracking sensors etc. Special cameras are also installed to take one or more pictures of the setup to correspond to each vector of data collected or at some other appropriate frequency. Herein, a vector is used to represent a set of data collected at a particular epoch or representative of the occupant or environment of vehicle at a particular point in time

A standard set of vehicle setups is chosen for initial trial data collection purposes. Typically, the initial trial will consist of between 20,000 and 100,000 setups, although this range is not intended to limit the invention.

Initial digital data collection now proceeds for the trial setup matrix. The data is collected from the transducers, digitized and combined to form to a vector of input data for analysis by a pattern recognition system such as a neural network program or combination neural network program. This analysis should yield a training accuracy of nearly 100%. If this is not achieved, then additional sensors are added to the system or the configuration changed and the data collection and analysis repeated.

In addition to a variety of seating states for objects in the passenger compartment, the trial database will also include environmental effects such as thermal gradients caused by heat lamps and the operation of the air conditioner and heater, or where appropriate lighting variations or other environmental variations that might affect particular transducer types. A sample of such a matrix is presented in FIGS. 24A-24H, with some of the variables and objects used in the matrix being designated or described in FIGS. 18-23D. After the neural network has been trained on the trial database, the trial database will be scanned for vectors that yield erroneous results (which would likely be considered bad data) A study of those vectors along with vectors from associated in time cases are compared with the photographs to determine whether there is erroneous data present. If so, an attempt is made to determine the cause of the erroneous data. If the cause can be found, for example if a voltage spike on the power line corrupted the data, then the vector will be removed from the database and an attempt is made to correct the data collection process so as to remove such disturbances.

At this time, some of the sensors may be eliminated from the sensor matrix. This can be determined during the neural network analysis, for example, by selectively eliminating sensor data from the analysis to see what the effect if any results. Caution should be exercised here, however, since once the sensors have been initially installed in the vehicle,

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it requires little additional expense to use all of the installed sensors in future data collection and analysis.

The neural network that has been developed in this first phase can be used during the data collection in the next phases as an instantaneous check on the integrity of the new vectors being collected. Occasionally, a voltage spike or other environmental disturbance will momentarily effect the data from some transducers. It is important to capture this event to first eliminate that data from the database and second to isolate the cause of the erroneous data.

The next set of data to be collected when neural networks are used, for example, is the training database. This will usually be the largest database initially collected and will cover such setups as listed, for example, in FIGS. 24A-24H. The training database, which may contain 500,000 or more vectors, will be used to begin training of the neural network or other pattern recognition system. In the foregoing description, a neural network will be used for exemplary purposes with the understanding that the invention is not limited to neural networks and that a similar process exists for other pattern recognition systems. This invention is largely concerned with the use of pattern recognition systems for vehicle internal monitoring. The best mode is to use trained pattern recognition systems such as neural networks. While this is taking place additional data will be collected according to FIGS. 20-22 and 25 of the independent and validation databases. The training database is usually selected so that it uniformly covers all seated states that are known to be likely to occur in the vehicle. The independent database may be similar in makeup to the training database or it may evolve to more closely conform to the occupancy state distribution of the validation database. During the neural network training, the independent database is used to check the accuracy of the neural network and to reject a candidate neural network design if its accuracy, measured against the independent database, is less than that of a previous network architecture.

Although the independent database is not actually used in the training of the neural network, nevertheless, it has been found that it significantly influences the network structure or architecture. Therefore, a third database, the validation or real world database, is used as a final accuracy check of the chosen system. It is the accuracy against this validation database that is considered to be the system accuracy. The validation database is usually composed of vectors taken from setups which closely correlate with vehicle occupancy in real cars on the roadway. Initially the training database is usually the largest of the three databases. As time and resources permit the independent database, which perhaps starts out with 100,000 vectors, will continue to grow until it becomes approximately the same size or even larger than the training database. The validation database, on the other hand, will typically start out with as few as 50,000 vectors. However, as the hardware configuration is frozen, the validation database will continuously grow until, in some cases, it actually becomes larger than the training database. This is because near the end of the program, vehicles will be operating on highways and data will be collected in real world situations. If in the real world tests, system failures are discovered this can lead to additional data being taken for both the training and independent databases as well as the validation database.

Once a neural network has been trained using all of the available data from all of the transducers, it is expected that the accuracy of the network will be very close to 100%. It is usually not practical to use all of the transducers that have been used in the training of the system for final installation

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in real production vehicle models. This is primarily due to cost and complexity considerations. Usually the automobile manufacturer will have an idea of how many transducers would be acceptable for installation in a production vehicle. For example, the data may have been collected using 20 different transducers but the automobile manufacturer may restrict the final selection to 6 transducers. The next process, therefore, is to gradually eliminate transducers to determine what is the best combination of six transducers, for example, to achieve the highest system accuracy. Ideally, a series of neural networks would be trained using all combinations of six transducers from the 20 available. The activity would require a prohibitively long time. Certain constraints can be factored into the system from the beginning to start the pruning process. For example, it would probably not make sense to have both optical and ultrasonic transducers present in the same system since it would complicate the electronics. In fact, the automobile manufacturer may have decided initially that an optical system would be too expensive and therefore would not be considered. The inclusion of optical transducers, therefore, serves as a way of determining the loss in accuracy as a function of cost. Various constraints, therefore, usually allow the immediate elimination of a significant number of the initial group of transducers. This elimination and the training on the remaining transducers provides the resulting accuracy loss that results.

The next step is to remove each of the transducers one at a time and determine which sensor has the least effect on the system accuracy. This process is then repeated until the total number of transducers has been pruned down to the number desired by the customer. At this point, the process is reversed to add in one at a time those transducers that were removed at previous stages. It has been found, for example, that a sensor that appears to be unimportant during the early pruning process can become very important later on. Such a sensor may add a small amount of information due to the presence of various other transducers. Whereas the various other transducers, however, may yield less information than still other transducers and, therefore may have been removed during the pruning process. Reintroducing the sensor that was eliminated early in the cycle therefore can have a significant effect and can change the final choice of transducers to make up the system.

The above method of reducing the number of transducers that make up the system is but one of a variety of approaches which have applicability in different situations. In some cases, a Monte Carlo or other statistical approach is warranted, whereas in other cases a design of experiments approach has proven to be the most successful. In many cases, an operator conducting this activity becomes skilled and after a while knows intuitively what set of transducers is most likely to yield the best results. During the process it is not uncommon to run multiple cases on different computers simultaneously. Also, during this process, a database of the cost of accuracy is generated. The automobile manufacturer, for example, may desire to have the total of 6 transducers in the final system, however, when shown the fact that the addition of one or two additional transducers substantially increases the accuracy of the system, the manufacturer may change his mind. Similarly, the initial number of transducers selected may be 6 but the analysis could show that 4 transducers give substantially the same accuracy as 6 and therefore the other 2 can be eliminated at a cost saving.

While the pruning process is occurring, the vehicle is subjected to a variety of road tests and would be subjected to presentations to the customer. The road tests are tests that are run at different locations than where the fundamental

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training took place. It has been found that unexpected environmental factors can influence the performance of the system and therefore these tests can provide critical information. The system, therefore, which is installed in the test vehicle should have the capability of recording system failures. This recording includes the output of all of the transducers on the vehicle as well as a photograph of the vehicle setup that caused the error. This data is later analyzed to determine whether the training, independent or validation setups need to be modified and/or whether the transducers or positions of the transducers require modification.

Once the final set of transducers has been chosen, the vehicle is again subjected to real world testing on highways and at customer demonstrations. Once again, any failures are recorded. In this case, however, since the total number of transducers in the system is probably substantially less than the initial set of transducers, certain failures are to be expected. All such failures, if expected, are reviewed carefully with the customer to be sure that the customer recognizes the system failure modes and is prepared to accept the system with those failure modes.

The system described so far has been based on the use of a single neural network. It is frequently necessary and desirable to use combination neural networks, multiple neural networks, cellular neural networks or support vector machines or other pattern recognition systems. For example, for determining the occupancy state of a vehicle seat there may be at least two different requirements. The first requirement is to establish what is occupying the seat and the second requirement is to establish where that object is located. Another requirement might be to simply determine whether an occupying item warranting analysis by the neural networks is present. Generally, a great deal of time, typically many seconds, is available for determining whether a forward facing human or an occupied or unoccupied rear facing child seat, for example, occupies the vehicle seat. On the other hand, if the driver of the car is trying to avoid an accident and is engaged in panic braking, the position of an unbelted occupant can be changing rapidly as he or she is moving toward the airbag. Thus, the problem of determining the location of an occupant is time critical. Typically, the position of the occupant in such situations must be determined in less than 20 milliseconds. There is no reason for the system to have to determine that a forward facing human being is in the seat while simultaneously determining where that forward facing human being is. The system already knows that the forward facing human being is present and therefore all of the resources can be used to determine the occupant's position. Thus, in this situation a dual level or modular neural network can be advantageously used. The first level determines the occupancy of the vehicle seat and the second level determines the position of that occupant. In some situations, it has been demonstrated that multiple neural networks used in parallel can provide some benefit. This will be discussed in more detail below. Both modular and multiple parallel neural networks are examples of combination neural networks.

The data that is fed to the pattern recognition system typically will usually not be the raw vectors of data as captured and digitized from the various transducers. Typically, a substantial amount of preprocessing of the data is undertaken to extract the important information from the data that is fed to the neural network. This is especially true in optical systems and where the quantity of data obtained, if all were used by the neural network, would require very expensive processors. The techniques of preprocessing data will not be described in detail here. However, the prepro-



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cessing techniques influence the neural network structure in many ways. For example, the preprocessing used to determine what is occupying a vehicle seat is typically quite different from the preprocessing used to determine the location of that occupant. Some particular preprocessing concepts will be discussed in more detail below.

Once the pattern recognition system has been applied to the preprocessed data, one or more decisions are available as output. The output from the pattern recognition system is usually based on a snapshot of the output of the various transducers. Thus, it represents one epoch or time period. The accuracy of such a decision can usually be substantially improved if previous decisions from the pattern recognition system are also considered. In the simplest form, which is typically used for the occupancy identification stage, the results of many decisions are averaged together and the resulting averaged decision is chosen as the correct decision. Once again, however, the situation is quite different for dynamic out-of-position. The position of the occupant must be known at that particular epoch and cannot be averaged with his previous position. On the other hand, there is information in the previous positions that can be used to improve the accuracy of the current decision. For example, if the new decision says that the occupant has moved six inches since the previous decision, and, from physics, it is known that this could not possibly take place, than a better estimate of the current occupant position can be made by extrapolating from earlier positions. Alternately, an occupancy position versus time curve can be fitted using a variety of techniques such as the least squares regression method, to the data from previous 10 epochs, for example. This same type of analysis could also be applied to the vector itself rather than to the final decision thereby correcting the data prior to its being entered into the pattern recognition system. An alternate method is to train a module of a modular neural network to predict the position of the occupant based on feedback from previous results of the module.

A pattern recognition system, such as a neural network, can sometimes make totally irrational decisions. This typically happens when the pattern recognition system is presented with a data set or vector that is unlike any vector that has been in its training set. The variety of seating states of a vehicle is unlimited. Every attempt is made to select from that unlimited universe a set of representative cases. Nevertheless, there will always be cases that are significantly different from any that have been previously presented to the neural network. The final step, therefore, to adapting a system to a vehicle, is to add a measure of human intelligence or common sense. Sometimes this goes under the heading of fuzzy logic and the resulting system has been termed in some cases a neural fuzzy system. In some cases, this takes the form of an observer studying failures of the system and coming up with rules and that say, for example, that if transducer A perhaps in combination with another transducer produces values in this range than the system should be programmed to override the pattern recognition decision and substitute therefor a human decision.

An example of this appears in R. Scorcioni, K. Ng, M. M. Trivedi, N. Lassiter; "MoNiF. A Modular Neuro-Fuzzy Controller for Race Car Navigation"; In Proceedings of the 1997 *IEEE Symposium on Computational Intelligence and Robotics Applications*, Monterey, Calif., USA July 1997 and describes the case of where an automobile was designed for autonomous operation and trained with a neural network, in one case, and a neural fuzzy system in another case. As long as both vehicles operated on familiar roads both vehicles performed satisfactorily. However, when placed on an unfa-

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miliar road, the neural network vehicle failed while the neural fuzzy vehicle continue to operate successfully. Naturally, if the neural network vehicle had been trained on the unfamiliar road, it might very well have operated successfully. Nevertheless, the critical failure mode of neural networks that most concerns people is this uncertainty as to what a neural network will do when confronted with an unknown state.

One aspect, therefore, of adding human intelligence to the system, is to ferret out those situations where the system is likely to fail. Unfortunately, in the current state-of-the-art, this is largely a trial and error activity. One example is that if the range of certain parts of vector falls outside of the range experienced during training, the system defaults to a particular state. In the case of suppressing deployment of one or more airbags, or other occupant protection apparatus, this case would be to enable airbag deployment even if the pattern recognition system calls for its being disabled. An alternate method is to train a particular module of a modular neural network to recognize good from bad data and reject the bad data before it is fed to the main neural networks.

The foregoing description is applicable to the systems described in the following drawings and the connection between the foregoing description and the systems described below will be explained below. However, it should be appreciated that the systems shown in the drawings do not limit the applicability of the methods or apparatus described above.

Referring to the accompanying drawings wherein like reference numbers designate the same or similar elements, FIG. 1 shows a passenger seat 1 to which an adjustment apparatus including a seated-state detecting system developed according to the present invention may be applied. The seat 1 includes a horizontally situated bottom seat portion 2 and a vertically oriented back portion 3. The seat portion 2 is provided with weight measuring means, such as one or more weight sensors 6 and 7, that determine the weight of the object occupying the seat, if any. The coupled portion between the seated portion 2 and the back portion 3 (also referred to as the seatback) is provided with a reclining angle detecting sensor 9, which detects the tilted angle of the back portion 3 relative to the seat portion 2. The seat portion 2 is provided with a seat track position-detecting sensor 10. The seat track position detecting sensor 10 fulfills a role of detecting the quantity of movement of the seat 1 which is moved from a back reference position, indicated by the dotted chain line. Embedded within the seatback 3 is a heartbeat sensor 31 and a motion sensor 33. Attached to the headliner of the vehicle is a capacitance sensor 32. The seat 1 may be the driver seat, the front passenger seat or any other seat in a motor vehicle as well as other seats in transportation vehicles or seats in non-transportation applications.

Motion sensor 33 can be a discrete sensor that detects relative motion in the passenger compartment of the vehicle. Such sensors are frequently based on ultrasonics and can measure a change in the ultrasonic pattern that occurs over a short time period. Alternately, the subtracting of one position vector from a previous position vector to achieve a differential position vector can detect motion. For the purposes herein, a motion sensor will be used to mean either a particular device that is designed to detect motion for the creation of a special vector based on vector differences.

The weight measuring means, such as the sensors 6 and 7, are associated with the seat, and can be mounted into or below the seat portion 2 or on the seat structure, for example, for measuring the weight applied onto the seat. The weight may be zero if no occupying item is present. Sensors 6 and

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7 may represent a plurality of different sensors which measure the weight applied onto the seat at different portions thereof or for redundancy purposes, for example, such as by means of an airbag or bladder 5 in the seat portion 2. The bladder 5 may have one or more compartments. Such sensors may be in the form of strain, force or pressure sensors which measure the force or pressure on the seat portion 2 or seat back 3, displacement measuring sensors which measure the displacement of the seat surface or the entire seat 1 such as through the use of strain gages mounted on the seat structural members, such as 7, or other appropriate locations, or systems which convert displacement into a pressure wherein a pressure sensor can be used as a measure of weight. Sensors 6 and 7 may be of the types disclosed in U.S. Pat. No. 6,242,701, incorporated by reference herein.

An ultrasonic, optical or other sensor or transducer system 12 is mounted on the upper portion of the front pillar, i.e., the A-Pillar, of the vehicle and a similar sensor system 11 is mounted on the upper portion of the intermediate pillar, i.e., the B-Pillar. Each sensor system 11,12 may comprise a transducer. The outputs of the sensor systems 11 and 12 can be input to a band pass filter 20 through a multiplex circuit 19 which can be switched in synchronization with a timing signal from the ultrasonic sensor drive circuit 18, for example, and then is amplified by an amplifier 21. The band pass filter 20 removes a low frequency wave component from the output signal and also removes some of the noise. The envelope wave signal can be input to an analog/digital converter (ADC) 22 and digitized as measured data. The measured data can be input to a processing circuit 23, which is controlled by the timing signal which is in turn output from the sensor drive circuit 18. The above description applies primarily to systems based on ultrasonics and will differ somewhat for optical, electric field and other systems

Neural network as used herein will generally mean a single neural network, a combination neural network, a cellular neural network, a support vector machine or any combinations thereof.

Each of the measured data is input to a normalization circuit 24 and normalized. The normalized measured data can be input to the combination neural network (circuit) 25, for example, as wave data.

The output of the weight sensor(s) 6 and 7 can be amplified by an amplifier 26 coupled to the weight sensor(s) 6 and 7 and the amplified output is input to an analog/digital converter and then directed to the neural network 25, for example, of the processor means. Amplifier 26 is useful in some embodiments but it may be dispensed with by constructing the sensors 6 and 7 to provide a sufficiently strong output signal, and even possibly a digital signal. One manner to do this would be to construct the sensor systems with appropriate electronics.

The reclining angle detecting sensor 9 and the seat track position-detecting sensor 10 are connected to appropriate electronic circuits. For example, a constant-current can be supplied from a constant-current circuit to the reclining angle detecting sensor 9, and the reclining angle detecting sensor 9 converts a change in the resistance value on the tilt of the back portion 3 to a specific voltage. This output voltage is input to an analog/digital converter 28 as angle data, i.e., representative of the angle between the back portion 3 and the seat portion 2. Similarly, a constant current can be supplied from a constant-current circuit to the seat track position detecting sensor 10 and the seat track position detecting sensor 10 converts a change in the resistance value based on the track position of the seat portion 2 to a specific

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voltage. This output voltage is input to an analog/digital converter 29 as seat track data. Thus, the outputs of the reclining angle-detecting sensor 9 and the seat track position-detecting sensor 10 are input to the analog/digital converters (ADC) 28 and 29, respectively. Each digital data value from the ADCs 28,29 is input to the neural network 25, for example. A more detailed description of this and similar systems can be found in the above-referenced patents and patent applications assigned to the current assignee, all of which are incorporated herein by reference. The system described above is one example of many systems that can be designed using the teachings of this invention for detecting the occupancy state of the seat of a vehicle.

The neural network 25 is directly connected to the ADCs 28 and 29, the ADC associated with amplifier 26 and the normalization circuit 24. As such, information from each of the sensors in the system (a stream of data) is passed directly to the neural network 25 for processing thereby. The streams of data from the sensors are not combined prior to the neural network 25 and the neural network is designed to accept the separate streams of data (e.g., at least a part of the data at each input node) and process them to provide an output indicative of the current occupancy state of the seat. The neural network 25 thus includes or incorporates a plurality of algorithms derived by training in the manners discussed above and below. Once the current occupancy state of the seat is determined, it is possible to control vehicular components or systems, such as the airbag system, in consideration of the current occupancy state of the seat.

A section of the passenger compartment of an automobile is shown generally as 100 in FIG. 2. A driver 101 of a vehicle sits on a seat 102 behind a steering wheel, not shown, and an adult passenger 103 sits on seat 104 on the passenger side. Two transmitter and/or receiver assemblies 110 and 111, also referred to herein as transducers, are positioned in the passenger compartment 100, one transducer 110 is arranged on the headliner adjacent or in proximity to the dome light and the other transducer 111 is arranged on the center of the top of the dashboard or instrument panel of the vehicle. The methodology leading to the placement of these transducers is important to the instant invention as explained in detail below. In this situation, the system developed in accordance with this invention will reliably detect that an occupant is sitting on seat 104 and deployment of the airbag is enabled in the event that the vehicle experiences a crash. Transducers 110, 111 are placed with their separation axis parallel to the separation axis of the head, shoulder and rear facing child seat volumes of occupants of an automotive passenger seat and in view of this specific positioning, are capable of distinguishing the different configurations. In addition to the transducers 110, 111, weight-measuring sensors 210, 211, 212, 214 and 215 are also present. These weight sensors may be of a variety of technologies including, as illustrated here, strain-measuring transducers attached to the vehicle seat support structure as described in more detail in U.S. Pat. No. 6,081,757, incorporated herein by reference. Naturally other weight systems can be utilized including systems that measure the deflection of, or pressure on, the seat cushion. The weight sensors described here are meant to be illustrative of the general class of weight sensors and not an exhaustive list of methods of measuring occupant weight.

In FIG. 3, a forward facing child seat 120 containing a child 121 replaces the adult passenger 103 as shown in FIG. 2. In this case, it is usually required that the airbag not be disabled in the event of an accident. However, in the event that the same child seat is placed in the rearward facing position as shown in FIG. 4, then the airbag is usually



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required to be disabled since deployment of the airbag in a crash can seriously injure or even kill the child. Furthermore, as illustrated in FIG. 5, if an infant 131 in an infant carrier 130 is positioned in the rear facing position of the passenger seat, the airbag should be disabled for the reasons discussed above. Instead of disabling deployment of the airbag, the deployment could be controlled to provide protection for the child, e.g., to reduce the force of the deployment of the airbag. It should be noted that the disabling or enabling of the passenger airbag relative to the item on the passenger seat may be tailored to the specific application. For example, in some embodiments, with certain forward facing child seats, it may in fact be desirable to disable the airbag and in other cases to deploy a depowered airbag. The selection of when to disable, depower or enable the airbag, as a function of the item in the passenger seat and its location, is made during the programming or training stage of the sensor system and, in most cases, the criteria set forth above will be applicable, i.e., enabling airbag deployment for a forward facing child seat and an adult in a proper seating position and disabling airbag deployment for a rearward facing child seat and infant and for any occupant who is out-of-position and in close proximity to the airbag module. The sensor system developed in accordance with the invention may however be programmed according to other criteria.

Several systems using other technologies have been devised to discriminate between the four cases illustrated above but none have shown a satisfactory accuracy or reliability of discrimination. Some of these systems appear to work as long as the child seat is properly placed on the seat and belted in. So called "tag systems", for example, whereby a device is placed on the child seat which is electromagnetically sensed by sensors placed within the seat can fail but can add information to the overall system. When used alone, they function well as long as the child seat is restrained by a seatbelt, but when this is not the case they have a high failure rate. Since the seatbelt usage of the population of the United States is only about 70% at the present time, it is quite likely that a significant percentage of child seats will not be properly belted onto the seat and thus children will be subjected to injury and death in the event of an accident.

This methodology will now be described as it relates primarily to wave type sensors such as those based on optics, ultrasonics or radar. A similar methodology applies to other transducer types and which will now be obvious to those skilled in the art after a review of the methodology described below.

The methodology of this invention was devised to solve this problem. To understand this methodology, consider two transmitters and receivers 110 and 111 (transducers) which are connected by an axis AB in FIG. 6. Each transmitter radiates a signal which is primarily confined to a cone angle, called the field angle, with its origin at the transmitter. For simplicity, assume that the transmitter and receiver are embodied in the same device although in some cases a separate device will be used for each function. When a transducer sends out a burst of waves, for example, to thereby irradiate the passenger compartment with radiation, and then receives a reflection or modified radiation from some object in the passenger compartment, the distance of the object from the transducer can be determined by the time delay between the transmission of the waves and the reception of the reflected or modified waves.

When looking at a single transducer, it may not be possible to determine the direction to the object which is

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reflecting or modifying the signal but it may be possible to know how far that object is from the transducer, that is a single transducer may enable a distance measurement but not a directional measurement. In other words, the object may be at a point on the surface of a three-dimensional spherical segment having its origin at the transducer and a radius equal to the distance. This will generally be the case for an ultrasonic transducer or other broad beam single pixel device. Consider two transducers, such as 110 and 111 in FIG. 6, and both transducers receive a reflection from the same object, which is facilitated by proper placement of the transducers, the timing of the reflections depends on the distance from the object to each respective transducer. If it is assumed for the purposes of this analysis that the two transducers act independently, that is, they only listen to the reflections of waves which they themselves transmitted (which may be achieved by transmitting waves at different frequencies), then each transducer enables the determination of the distance to the reflecting object but not its direction. If we assume that the transducer radiates in all directions within the field cone angle, each transducer enables the determination that the object is located on a spherical surface A', B' a respective known distance from the transducer, that is, each transducer enables the determination that the object is a specific distance from that transducer which may or may not be the same distance between the other transducer and the same object. Since now there are two transducers, and the distance of the reflecting object has been determined relative to each of the transducers, the actual location of the object resides on a circle which is the intersection of the two spherical surfaces A', and B'. This circle is labeled C in FIG. 6. At each point along circle C, the distance to the transducer 110 is the same and the distance to the transducer 111 is the same. This, of course, is strictly true only for ideal one-dimensional objects.

For many cases, the mere knowledge that the object lies on a particular circle is sufficient since it is possible to locate the circle such that the only time that an object lies on a particular circle that its location is known. That is, the circle which passes through the area of interest otherwise passes through a volume where no objects can occur. Thus, the mere calculation of the circle in this specific location, which indicates the presence of the object along that circle, provides valuable information concerning the object in the passenger compartment which may be used to control or affect another system in the vehicle such as the airbag system. This of course is based on the assumption that the reflections to the two transducers are in fact from the same object. Care must be taken in locating the transducers such that other objects do not cause reflections that could confuse the system.

FIG. 7, for example, illustrates two circles D and E of interest which represent the volume which is usually occupied when the seat is occupied by a person not in a child seat, C, or by a forward facing child seat and the volume normally occupied by a rear facing child seat, respectively. Thus, if the circle generated by the system, (i.e., by appropriate processor means which receives the distance determination from each transducer and creates the circle from the intersection of the spherical surfaces which represent the distance from the transducers to the object) is at a location which is only occupied by an adult passenger, the airbag would not be disabled since its deployment in a crash is desired. On the other hand, if a circle is at a location occupied only by a rear facing child seat, the airbag would be disabled.

The above discussion of course is simplistic in that it does not take into account the volume occupied by the object or

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the fact the reflections from more than one object surface will be involved. In reality, transducer B is likely to pick up the rear of the occupant's head and transducer A, the front. This makes the situation more difficult for an engineer looking at the data to analyze. It has been found that pattern recognition technologies are able to extract the information from these situations and through a proper application of these technologies, an algorithm can be developed, which when installed as part of the system for a particular vehicle, the system accurately and reliably differentiates between a forward facing and rear facing child seat, for example, or an in-position or out-of-position forward facing human being.

From the above discussion, a method of transducer location is disclosed which provides unique information to differentiate between (i) a forward facing child seat or a forward properly positioned occupant where airbag deployment is desired and (ii) a rearward facing child seat and an out-of-position occupant where airbag deployment is not desired. In actuality, the algorithm used to implement this theory does not directly calculate the surface of spheres or the circles of interaction of spheres. Instead, a pattern recognition system is used to differentiate airbag-deployment desired cases from those where the airbag should not be deployed. For the pattern recognition system to accurately perform its function, however, the patterns presented to the system must have the requisite information. That is, for example, a pattern of reflected waves from an occupying item in a passenger compartment to various transducers must be uniquely different for cases where airbag deployment is desired from cases where deployment is not desired. The theory described above and in more detail below teaches how to locate transducers within the vehicle passenger compartment so that the patterns of reflected waves, for example, will be easily distinguishable for cases where airbag deployment is desired from those where deployment is not desired. In the case presented thus far, it has been shown that in some implementations the use of only two transducers can result in the desired pattern differentiation when the vehicle geometry is such that two transducers can be placed such that the circles D (airbag enabled) and E (airbag disabled) fall outside of the transducer field cones except where they are in the critical regions where positive identification of the condition occurs. Thus, the aiming and field angles of the transducers are important factors to determine in adapting a system to a particular vehicle, especially for ultrasonic and radar sensors, for example

The use of only two transducers in a system is typically not acceptable since one or both of the transducers can be rendered inoperable by being blocked, for example, by a newspaper. Thus, it is usually desirable to add a third transducer 112 as shown in FIG. 8 which now provides a third set of spherical surfaces relative to the third transducer. Transducer 112 is positioned on the passenger side of the A-pillar (which is a preferred placement if the system is designed to operate on the passenger side of the vehicle). Three spherical surfaces now intersect in only two points and in fact, usually at one point if the aiming angles and field angles are properly chosen. Once again, this discussion is only strictly true for a point object. For a real object, the reflections will come from different surfaces of the object, which usually are at similar distances from the object. Thus, the addition of a third transducer substantially improves system reliability. Finally, with the addition of a fourth transducer 113 as shown in FIG. 9, even greater accuracy and reliability is attained. Transducer 113 can be positioned on the ceiling of the vehicle close to the passenger side door.

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In FIG. 9, lines connecting the transducers C and D and the transducers A and B are substantially parallel permitting an accurate determination of asymmetry and thereby object rotation. Thus, for example, if the infant seat is placed on an angle as shown in FIG. 5, this condition can be determined and taken into account when the decision is made to disable the deployment of the airbag.

The discussion above has centered on locating transducers and designing a system for determining whether the two target volumes, that adjacent the airbag and that adjacent the upper portion of the vehicle seat, are occupied. Other systems have been described in the above referenced patents using a sensor mounted on or adjacent the airbag module and a sensor mounted high in the vehicle to monitor the space near the vehicle seat. Such systems use the sensors as independent devices and do not use the combination of the two sensors to determine where the object is located. In fact, the location of such sensors is usually poorly chosen so that it is easy to blind either or both with a newspaper for those transducers using high frequency electromagnetic waves or ultrasonic waves, for example. Furthermore, no system is known to have been disclosed, except in patents and patent applications assigned to the assignee of this invention, which uses more than two transducers especially in such a manner that one or more can be blocked without causing serious deterioration of the system. Again, the examples here have been for the purpose of suppressing the deployment of the airbag when it is necessary to prevent injury. The sensor system disclosed can be used for many other purposes such as disclosed in the above-mentioned patent applications assigned to the same assignee as the instant invention. The ability to use the sensors for these other applications is generally lacking in the systems disclosed in the other referenced patents.

Considering once again the condition of FIGS. 2-7 where two transducers are used, a plot can be made showing the reflection times of the objects which are located in the region of curve E and curve F of FIG. 7. This plot is shown on FIG. 10 where the c's represent reflections from rear facing child seats from various tests where the seats were placed in a variety of different positions and similarly the s's and h's represent shoulders and heads respectively of various forward facing human occupants. In these results from actual experiments using ultrasonic transducers, the effect of body thickness is present and yet the results still show that the basic principles of separation of key volumes are valid. Note that there is a region of separation between corridors that house the different object classes. It is this fact which is used in conjunction with neural networks, as described in the above referenced patent applications, which permit the design of a system that provides an accurate discrimination of rear facing child seats from forward facing humans. Heretofore before the techniques for locating the transducers to separate these two zones were discovered, the entire discrimination task was accomplished using neural networks. There was significant overlap between the reflections from the various objects and therefore separation was done based on patterns of the reflected waves. By using the technology described herein to carefully position and orient the transducers so as to create this region of separation of the critical surfaces, wherein all of the rear facing child seat data falls within a known corridor, the task remaining for the neural networks is substantially simplified with the result that the accuracy of identification is substantially improved.

Three general classes of child seats exist as well as several models which are unique. First, there is the infant only seat as shown in FIG. 5 which is for occupants weighing up to

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about 20 pounds. This is designed to be only placed in the rear facing position. The second which is illustrated in FIGS. 2 and 3 is for children from about 20 to about 40 pounds and can be used in both the forward and rear facing position and the third is for use only in the forward facing position and is for children weighing over about 40 pounds. All of these seats as well as the unique models are used in test setups according to this invention for adapting a system to a vehicle. For each child seat, there are several hundred unique orientations representing virtually every possible position of that seat within the vehicle. Tests are run, for example, with the seat tilted 22 degrees, rotated 17 degrees, placed on the front of the seat with the seat back fully up with the seat fully back and with the window open as well as all variations of these parameters. A large number of cases are also run, when practicing the teachings of this invention, with various accessories, such as clothing, toys, bottles, blankets etc., added to the child seat.

Similarly, wide variations are used for the occupants including size, clothing and activities such as reading maps or newspapers, leaning forward to adjust the radio, for example. Also included are cases where the occupant puts his/her feet on the dashboard or otherwise assumes a wide variety of unusual positions. When all of the above configurations are considered along with many others not mentioned, the total number of configurations which are used to train the pattern recognition system can exceed 500,000. The goal is to include in the configuration training set representations of all occupancy states that occur in actual use. Since the system is highly accurate in making the correct decision for cases which are similar to those in the training set, the total system accuracy increases as the size of the training set increases providing the cases are all distinct and not copies of other cases.

In addition to all of the variations in occupancy states, it is important to consider environmental effects during the data collection. Thermal gradients or thermal instabilities are particularly important for systems based on ultrasound since sound waves can be significantly diffracted by density changes in air. There are two aspects of the use of thermal gradients or instability in training. First, the fact that thermal instabilities exist and therefore data with thermal instabilities present should be part of database. For this case, a rather small amount of data collected with thermal instabilities would be used. A much more important use of thermal instability comes from the fact that they add variability to data. Thus, considerably more data is taken with thermal instability and in fact, in some cases a substantial percentage of the database is taken with time varying thermal gradients in order to provide variability to the data so that the neural network does not memorize but instead generalizes from the data. This is accomplished by taking the data with a cold vehicle with the heater operating and with a hot vehicle with the air conditioner operating. Additional data is also taken with a heat lamp in a closed vehicle to simulate a stable thermal gradient caused by sun loading.

To collect data for 500,000 vehicle configurations is not a formidable task. A trained technician crew can typically collect data on in excess on 2000 configurations or vectors per hour. The data is collected typically every 50 to 100 milliseconds. During this time, the occupant is continuously moving, assuming a continuously varying position and posture in the vehicle including moving from side to side, forward and back, twisting his/her head, reading newspapers and books, moving hands, arms, feet and legs, until the desired number of different seated state examples are obtained. In some cases, this process is practiced by con-

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fining the motion of an occupant into a particular zone. In some cases, for example, the occupant is trained to exercise these different seated state motions while remaining in a particular zone that may be the safe zone, the keep out zone, or an intermediate gray zone. In this manner, data is collected representing the airbag disable, depowered airbag enabled or full power airbag enabled states. In other cases, the actual position of the back of the head and/or the shoulders of the occupant are tracked using string pots, high frequency ultrasonic transducers, or optically. In this manner, the position of the occupant can be measured and the decision as to whether this should be a disable or enable airbag case can be decided later. By continuously monitoring the occupant, an added advantage results in that the data can be collected to permit a comparison of the occupant from one seated state to another. This is particularly valuable in attempting to project the future location of an occupant based on a series of past locations as would be desirable for example to predict when an occupant would cross into the keep out zone during a panic braking situation prior to crash.

It is important to note that it is not necessary to tailor the system for every vehicle produced but rather to tailor it for each platform. A platform is an automobile manufacturer's designation of a group of vehicle models that are built on the same vehicle structure.

A review of the literature on neural networks yields the conclusion that the use of such a large training set is unique in the neural network field. The rule of neural networks is that there must be at least three training cases for each network weight. Thus, for example, if a neural network has 156 input nodes, 10 first hidden layer nodes, 5 second hidden layer nodes, and one output node this results in a total of 1,622 weights. According to conventional theory 5000 training examples should be sufficient. It is highly unexpected, therefore, that greater accuracy would be achieved through 100 times that many cases. It is thus not obvious and cannot be deduced from the neural network literature that the accuracy of the system will improve substantially as the size of the training database increases even to tens of thousands of cases. It is also not obvious looking at the plots of the vectors obtained using ultrasonic transducers that increasing the number of tests or the database size will have such a significant effect on the system accuracy. Each of the vectors is typically a rather coarse plot with a few significant peaks and valleys. Since the spatial resolution of an ultrasonic system is typically about 2 to 4 inches, it is once again surprising that such a large database is required to achieve significant accuracy improvements.

An example of a combination neural network is shown generally at 250 in FIG. 12. The process begins at 252 with the acquisition of new data. This could be from a variety of sources such as multiple cameras, ultrasonic sensors, capacitive sensors, other electromagnetic field monitoring sensors, and other electric and/or magnetic or acoustic-based wave sensors. Additionally, the data can come from other sources such as weight or other morphological characteristic detecting sensors, occupant-presence detecting sensors, chemical sensors or seat position sensors. The data is preprocessed and fed into neural network at 254 where the type of occupying item is determined. If the network determines that the type of occupying item is either an empty seat or a rear facing child seat then control is passed to box 270 via line 256 and the decision is made to disable the airbag. It is envisioned though that instead of disabling deployment if a rear-facing child seat is present, a depowered deployment, a late deployment or a oriented deployment may be made if it is determined that such would more likely prevent injury to the child in the child seat than cause harm.



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In the event that the occupant type classification neural network **254** has determined that the seat is occupied by something other than a rear-facing child seat, then control is transferred to neural network **258**, occupant size classification, which has the task of determining whether the occupant is a small, medium or large occupant. It has been found that the accuracy of the position determination is improved if the occupant size is first classified and then a special occupant position neural network is used to monitor the position of the occupant relative to airbag module. Nevertheless, the order of applying the neural networks, e.g., the size classification prior to the position classification, is not critical to the practice of the invention. Once the size of the occupant has been classified by a neural network at **258**, control is then passed to neural networks **260**, **262**, or **264** depending on the output size determination from neural network **258**. The chosen network then determines the position of the occupant and that position determination is fed to the feedback delay algorithm **266** and to the decision to disable algorithm **270**. The feedback delay **266** can be a function of occupant size as well as the rate at which data is acquired. The results of the feedback delay algorithm **266** are fed to the appropriate large, medium or small occupant position neural networks **260**, **262** or **264**. It has been found that if the previous position of the occupant is used as input to the neural network that a more accurate estimation of the present position results. In some cases, multiple previous position values are fed instead of only the most recent value. This is determined for a particular application and programmed as part as of the feedback delay algorithm **266**. After the decision to disable has been made in algorithm **270**, control is returned to algorithm **252** via line **272** to acquire new data.

FIG. **12** is a singular example of an infinite variety combination neural networks that can be employed. This case combines a modular neural network structure with serial and parallel architectures. Feedback has also been used in a similar manner as a cellular neural network. Other examples include situations where imprecise data requires the input data to be divided into subsets and fed to a series of neural networks operating in parallel. The output of these neural networks can then be combined in a voting or another analytical manner to determine the final decision, e.g., whether and how to deploy the occupant protection apparatus. In other cases, particular transducers are associated with particular neural networks and the data combined after initial process by those dedicated neural networks. In still other cases, as discussed above, an initial neural network is used to determine whether the data to be analyzed is part of the same universe of data that has been used to train the networks. Sometimes transducers provide erroneous data and sometimes the wiring in the vehicle can be a source of noise that can corrupt the data. Similarly, a neural network is sometimes used as part of the decision to disable activity to compare results over time to again attempt to eliminate spurious false decisions. Thus, an initial determination as to whether the data is consistent with data on which the neural network is trained is often an advisable step.

In each of the boxes in FIG. **12**, with the exception of the decision to disable box **270** and the feedback delay box **266**, it has been assumed that each box would be a neural network. In many cases, a deterministic algorithm can be used, and in other cases correlation analysis, fuzzy logic or neural fuzzy systems, a support vector machine, a cellular neural network or any other pattern recognition algorithm or system are appropriate. Therefore, a combination neural network can include non-neural network analytical tasks.

FIG. **12** illustrates the use of a combination neural network to determine whether and how to deploy or disable an

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airbag. It must be appreciated that the same architecture may be used to determine whether and how to deploy any type of occupant protection apparatus which is defined herein as any device, apparatus, system or component which is actuatable or deployable or includes a component which is actuatable or deployable for the purpose of attempting to minimize injury to the occupant in the event of a crash involving the vehicle. More generally, the architecture shown in FIG. **12** may be used simply to determine the occupancy state of the vehicle, e.g., the type, size and position of the occupant. A determination of the occupancy state of the vehicle includes a determination of any or all of the occupant's type, identification, size, position, etc. The occupancy state can then be used to in the control of any vehicular component, system or subsystem.

FIG. **13** shows a more general schematic illustration of the use of a combination neural network, or a combination pattern recognition network, designated **309** in accordance with the invention. Data is acquired at **300** and input into the occupancy state determination unit, i.e., the combination neural network, which provides an indication of the occupancy state of the seat. Once the occupancy state is determined at **302**, it is provided to the component control unit **304** to effect control of the component. A feedback delay **306** is provided to enable the determination of the occupancy state from one instance to be used by the combination neural network at a subsequent instance. After the component control **304** is effected, the process begins anew by acquiring new data via line **308**.

FIG. **14** shows a schematic illustration of the use of a combination neural network in accordance with the invention designated **324** in which the occupancy state determination entails an identification of the occupying item by one neural network and a determination of the position of the occupying item by one or more other neural network. Data is acquired at **310** and input into the identification neural network **312** which is trained to provide the identification of the occupying item of the seat based on at least some of the data, i.e., data from one or more transducers might have been deemed of nominal relevance for the identification determination and thus the identification neural network **312** was not trained on such data. Once the identification of the occupying item is determined at **312**, it is provided to one of the position neural networks **314** which is trained to provide an indication of the position of the occupying item, e.g., relative to the occupant protection apparatus, based on at least some of the data. That is, data from one or more transducers, although possibly useful for the identification neural network **312**, might have been deemed of nominal relevance for the position neural network **314** and thus the position neural network was not trained on such data. Once the identification and position of the occupying item are determined, they are provided to the component control unit **316** to effect control of the component based on one of these determinations or both. A feedback delay **318** is provided for the identification neural network **312** to enable the determination of the occupying item's identification from one instance to be used by the identification neural network **312** at a subsequent instance. A feedback delay **320** is provided for the position neural network **314** to enable the determination of the occupying item's position from one instance to be used by the position neural network **314** at a subsequent instance. After the component control **316** is effected, the process begins anew by acquiring new data via line **322**. The identification neural network **312**, the position determination neural network **314** and feedback delays **318**, **320** combine to constitute the combination neural network **324** in this embodiment (shown in dotted lines).

The data used by the identification neural network **312** to determine the identification of the occupying item may be different than the data used by the position determination

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neural network 314 to determine the position of the occupying item. That is, data from a different set of transducers may be applied by the identification neural network 312 than by the position determination neural network. Instead of a single position determination neural network as schematically shown in FIG. 14, a plurality of position determination neural networks may be used depending on the identification of the occupying item. Also, a size determination neural network may be incorporated into the combination neural network after the identification neural network 312 and then optionally, a plurality of the position determination neural networks as shown in the embodiment of FIG. 12.

With respect to the feedback delays 318,320, it is possible to use the position determination from position neural network 314 as input into the identification neural network 312.

FIG. 15 shows a schematic illustration of the use of a combination neural network in accordance with the invention designated 338 in which the occupancy state determination entails an initial determination as to the quality of the data obtained by the transducers and intended for input into a main occupancy state determination neural network. Data from the transducers is acquired at 326 and input into a gating neural network 328 which is trained to allow only data which agrees with or is similar to data on which a main neural network 330 is trained. If the data provided by transducers has been corrupted and thus deviates from data on which the main neural network 330 has been trained, the gating neural network 328 will reject it and request new data via line 342 from the transducers. Thus, gating neural network 328 serves as a gate to prevent data which might cause an incorrect occupancy state determination from entering as input to the main neural network 330. If the gating neural network 328 determines that the data is reasonable, it allows the data to pass as input to the main neural network 330 which is trained to determine the occupancy state. Once the occupancy state is determined, it is provided to the component control unit 332 to effect control of the component. A feedback delay 336 is provided for the gating neural network 328 to enable the indication of unreasonable data from one instance to be used by the gating neural network 328 at a subsequent instance. A feedback delay 334 is provided for the main neural network 330 to enable the determination of the occupancy state from one instance to be used by the main neural network 330 at a subsequent instance. After the component control 332 is effected, the process begins anew by acquiring new data via line 340. The gating neural network 328, the main neural network 330 and optional feedback delays 334,336 combine to constitute the combination neural network 338 in this embodiment (shown in dotted lines).

Instead of a single occupancy state neural network as schematically shown in FIG. 15, the various combinations of neural networks disclosed herein for occupancy state determination may be used. Similarly, the use of a gating neural network, or a fuzzy logic algorithm or other algorithm, may be incorporated into any of the combination neural networks disclosed herein to prevent unreasonable data from entering into any of the neural networks in any of the combination neural networks.

FIG. 16 shows a schematic illustration of the use of a combination neural network in accordance with the invention designated 344 with a particular emphasis on determining the orientation and position of a child seat. Data is acquired at 346 and input into the identification neural network 348 which is trained to provide the identification of the occupying item of the seat based on at least some of the data. If the occupying item is other than a child seat, the process is directed to size/position determination neural network 350 which is trained to determine the size and position of the occupying item and pass this determination to the component control 352 to enable control of the

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component to be effected based on the identification, size and/or position of the occupying item. Note that the size/position determination neural network may itself be a combination neural network.

When the occupying item is identified as a child seat, the process passes to orientation determination neural network 354 which is trained to provide an indication of the orientation of the child seat, i.e., whether it is rear-facing or forward-facing, based on at least some of the data. That is, data from one or more transducers, although possibly useful for the identification neural network 348, might have been deemed of nominal relevance for the orientation determination neural network 354 and thus the orientation neural network was not trained on such data. Once the orientation of the child seat is determined, control is then passed to position determination neural networks 356,358 depending on the orientation determination from neural network 354. The chosen network then determines the position of the child seat and that position determination is passed to component control 352 to effect control of the component.

A feedback delay 360 can be provided for the identification neural network 348 to enable the determination of the occupying item's identification from one instance to be used by the identification neural network 348 at a subsequent instance. A feedback delay 362 is provided for the orientation determination neural network 354 to enable the determination of the child seat's orientation from one instance to be used by the orientation determination neural network 354 at a subsequent instance. A feedback delay 364 can be provided for the position determination neural networks 356,358 to enable the position of the child seat from one instance to be used by the respective position determination neural networks 356,358 at a subsequent instance. After the component control 352 is effected, the process begins anew by acquiring new data via line 366. The identification neural network 348, the position/size determination neural network 350, the child seat orientation determination neural network 354, the position determination neural networks 356,358 and the feedback delays 360,362,364 combine to constitute the combination neural network 344 in this embodiment (shown in dotted lines).

The data used by the identification neural network 348 to determine the identification of the occupying item, the data used by the position/size determination neural network 350 to determine the position of the occupying item, the data used by the orientation determination neural network 354, the data used by the position determination neural networks 356,358 may all be different from one another. For example, data from a different set of transducers may be applied by the identification neural network 348 than by the position/size determination neural network 350. As mentioned above, instead of a single position/size determination neural network as schematically shown in FIG. 14, a plurality of position determination neural networks may be used depending on the identification of the occupying item.

With respect to the feedback delays 360,362,364, it is possible to provide either upstream or downstream feedback from any of the neural networks to any of the other neural networks.

FIG. 17 shows a schematic illustration of the use of an ensemble type of combination neural network in accordance with the invention designated 368. Data from the transducers is acquired at 370 and three streams of data are created. Each stream of data contains data from a different subset of transducers. Each stream of data is input into a respective occupancy determination neural network 372,374,376, each of which is trained to determine the occupancy state based on the data from the respective subset of transducers. Once the occupancy state is determined by each neural network 372,374,376, it is provided to a voting determination system 378 to consider the determination of the occupancy states

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from the occupancy determination neural networks 372,374, 376 and determine the most reasonable occupancy state which is passed to the component control unit 380 to effect control of the component. Ideally, the occupancy state determined by each neural network 372,374,376 will be the same and such would be passed to the component control. However, in the event they differ, the voting determination system 378 weighs the occupancy states determined by each neural network 372,374,376 and "votes" for one. For example, if two neural networks 372,374 provided the same occupancy state while neural network 376 provides a different occupancy state, the voting determination system 378 could be designed to accept the occupancy state from the majority of neural networks, in this case, that of neural networks 372,374. A feedback delay may be provided for each neural network 372,374,376 as well as from the voting determination system 378 to each neural network 372,374, 376. The voting determination system 378 may itself be a neural network. After the component control 380 is effected, the process begins anew by acquiring new data via line 382

Instead of the single occupancy state neural networks 372,374,376 as schematically shown in FIG. 17, the various combinations of neural networks disclosed herein for occupancy state determination may be used.

#### Process for Training a Vehicle

The process for adapting an ultrasonic system to a vehicle will now be described. A more detailed list of steps is provided in Appendix 2. Although the pure ultrasonic system is described here, a similar or analogous set of steps applies when other technologies such as weight and optical (scanning or imager) or other electromagnetic wave or electric field systems such as capacitance and field monitoring systems are used. This description is thus provided to be exemplary and not limiting.

1. Select transducer, horn and grill designs to fit the vehicle. At this stage, usually full horns are used which are mounted so that they project into the passenger compartment. No attempt is made at this time to achieve an esthetic matching of the transducers to the vehicle surfaces. An estimate of the desired transducer fields is made at this time either from measurements in the vehicle directly or from CAD drawings
2. Make polar plots of the transducer sonic fields. Transducers and candidate horns and grills are assembled and tested to confirm that the desired field angles have been achieved. This frequently requires some adjustment of the transducers in the horn and of the grill. A properly designed grill for ultrasonic systems can perform a similar function as a lens for optical systems.
3. Check to see that the fields cover the required volumes of the vehicle passenger compartment and do not impinge on adjacent flat surfaces that may cause multipath effects. Redesign horns and grills if necessary.
4. Install transducers into vehicle.
5. Map transducer fields in the vehicle and check for multipath effects and proper coverage.
6. Adjust transducer aim and re-map fields if necessary.
7. Install daily calibration fixture and take standard setup data.
8. Acquire 50,000 to 100,000 vectors
9. Adjust vectors for volume considerations by removing some initial data points if cross talk or ringing is present and some final points to keep data in the desired passenger compartment volume.
10. Normalize vectors.
11. Run neural network algorithm generating software to create algorithm for vehicle installation.
12. Check the accuracy of the algorithm. If not sufficiently accurate collect more data where necessary and retrain.

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If still not sufficiently accurate, add additional transducers to cover holes.

13. When sufficient accuracy is attained, proceed to collect ~500,000 training vectors varying: Occupancy (see Appendices 1 and 3):
  - Occupant size, position (zones), clothing etc
  - Child seat type, size, position etc.
  - Empty seat
- Vehicle configuration:
  - Seat position
  - Window position
  - Visor and armrest position
  - Presence of other occupants in adjoining seat or rear seat
  - Temperature
  - Temperature gradient—stable
  - Temperature turbulence—heater and air conditioner
  - Wind turbulence—High speed travel with windows open, top down etc.
14. Collect ~100,000 vectors of Independent data using other combinations of the above
15. Collect ~50,000 vectors of "real world data" to represent the acceptance criteria and more closely represent the actual seated state probabilities in the real world.
16. Train network and create an algorithm using the training vectors and the Independent data vectors.
17. Validate the algorithm using the real world vectors.
18. Install algorithm into the vehicle and test.
19. Decide on post processing methodology to remove final holes (areas of inaccuracy) in system
20. Implement post-processing methods into the algorithm
21. Final test. The process up until step 13 involves the use of transducers with full horns mounted on the surfaces of the interior passenger compartment. At some point, the actual transducers which are to be used in the final vehicle must be substituted for the trial transducers. This is either done prior to step 13 or at this step. This process involves designing transducer holders that blend with the visual surfaces of the passenger compartment so that they can be covered with a properly designed grill that helps control the field and also serves to retain the esthetic quality of the interior. This is usually a lengthy process and involves several consultations with the customer. Usually, therefore, the steps from 13 through 20 are repeated at this point after the final transducer and holder design has been selected. The initial data taken with full horns gives a measure of the best system that can be made to operate in the vehicle. Some degradation in performance is expected when the esthetic horns and grills are substituted for the full horns. By conducting two complete data collection cycles an accurate measure of this accuracy reduction can be obtained.
22. Up until this point, the best single neural network algorithm has been developed. The final step is to implement the principles of a combination neural network in order to remove some remaining error sources such as bad data and to further improve the accuracy of the system. It has been found that the implementation of combination neural networks can reduce the remaining errors by up to 50 percent. A combination neural network CAD optimization program provided by International Scientific Research Inc. can now be used to derive the neural network architecture. Briefly, the operator lays out a combination neural network involving many different neural networks arranged in parallel



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and in series and with appropriate feedbacks which the operator believes could be important. The software then optimizes each neural network and also provides an indication of the value of the network. The operator can then selectively eliminate those networks with little or no value and retrain the system. Through this combination of pruning, retraining and optimizing the final candidate combination neural network results.

23. Ship to customers to be used in production vehicles.

24. Collect additional real world validation data for continuous improvement.

More detail on the operation of the transducers and control circuitry as well as the neural network is provided in the above referenced patents and patent applications and is incorporated herein as if the entire text of the same were reproduced here. One particular example of a successful neural network for the two transducer case had 78 input nodes, 6 hidden nodes and one output node and for the four transducer case had 176 input nodes 20 hidden layer nodes on hidden layer one, 7 hidden layer nodes on hidden layer 2 and one output node. The weights of the network were determined by supervised training using the back propagation method as described in the referenced patent applications and in more detail in the references cited therein. Naturally other neural network architectures are possible including RCE, Logicon Projection, Stochastic, cellular, or support vector machine, etc. An example of a combination neural network system is shown in FIG. 12. Any of the network architectures mention here can be used for any of the boxes in FIG. 12.

Finally, the system is trained and tested with situations representative of the manufacturing and installation tolerances that occur during the production and delivery of the vehicle as well as usage and deterioration effects. Thus, for example, the system is tested with the transducer mounting positions shifted by up to one inch in any direction and rotated by up to 5 degrees, with a simulated accumulation of dirt and other variations. This tolerance to vehicle variation also sometimes permits the installation of the system onto a different but similar model vehicle with, in many cases, only minimal retraining of the system.

The speed of sound varies with temperature, humidity, and pressure. This can be compensated for by using the fact that the geometry between the transducers is known and the speed of sound can therefore be measured. Thus, on vehicle startup and as often as desired thereafter, the speed of sound can be measured by one transducer, such as transducer 110 in FIG. 5, sending a signal which is directly received by another transducer. Since the distance separating them is known, the speed of sound can be calculated and the system automatically adjusted to remove the variation due to the change in the speed of sound. Therefore, the system operates with same accuracy regardless of the temperature, humidity or atmospheric pressure. It may even be possible to use this technique to also automatically compensate for any effects due to wind velocity through an open window. An additional benefit of this system is that it can be used to determine the vehicle interior temperature for use by other control systems within the vehicle since the variation in the velocity of sound is a strong function of temperature and a weak function of pressure and humidity.

The problem with the speed of sound measurement described above is that some object in the vehicle may block the path from one transducer to another. This of course could be checked and a correction not be made if the signal from one transducer does not reach the other transducer. The problem, however, is that the path might not be completely blocked but only slightly blocked. This would cause the ultrasonic path length to increase, which would give a false indication of a temperature change. This can be solved by using more than one transducer. All of the transducers can

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broadcast signals to all of the other transducers. The problem here, of course, is which transducer pair does one believe if they all give different answers. The answer is the one that gives the shortest distance or the greatest calculated speed of sound. By this method, there are a total of 6 separate paths for four ultrasonic transducers.

An alternative method of determining the temperature is to use the transducer circuit to measure some parameter of the transducer that changes with temperature. For example the natural frequency of ultrasonic transducers changes in a known manner with temperature and therefore by measuring the natural frequency of the transducer the temperature can be determined. Since this method does not require communication between transducers, it would also work in situations where each transducer has a different resonant frequency.

The process, by which all of the distances are carefully measured from each transducer to the other transducers, and the algorithm developed to determine the speed of sound, is a significant part of the teachings of the instant invention for use with ultrasonic transducers. Prior to this, the speed of sound calculation was based on a single transmission from one transducer to a known second transducer. This resulted in an inaccurate system design and degraded the accuracy of systems in the field.

If the electronic control module that is part of the system is located in generally the same environment as the transducers, another method of determining the temperature is available. This method utilizes a device and whose temperature sensitivity is known and which is located in the same box as the electronic circuit. In fact, in many cases, an existing component on the printed circuit board can be monitored to give an indication of the temperature. For example, the diodes in a log comparison circuit have characteristics that their resistance changes in a known manner with temperature. It can be expected that the electronic module will generally be at a higher temperature than the surrounding environment, however, the temperature difference is a known and predictable amount. Thus, a reasonably good estimation of the temperature in the passenger compartment can also be obtained in this manner. Naturally, thermistors or other temperature transducers can be used.

Another important feature of a system, developed in accordance with the teachings of this invention, is the realization that motion of the vehicle can be used in a novel manner to substantially increase the accuracy of the system. Ultrasonic waves reflect on most objects as light off a mirror. This is due to the relatively long wavelength of ultrasound as compared with light. As a result, certain reflections can overwhelm the receiver and reduce the available information. When readings are taken while the occupant and/or the vehicle is in motion, and these readings averaged over several transmission/reception cycles, the motion of the occupant and vehicle causes various surfaces to change their angular orientation slightly but enough to change the reflective pattern and reduce this mirror effect. The net effect is that the average of several cycles gives a much clearer image of the reflecting object than is obtainable from a single cycle. This then provides a better image to the neural network and significantly improves the identification accuracy of the system. The choice of the number of cycles to be averaged depends on the system requirements. For example, if dynamic out-of-position is required then each vector must be used alone and averaging in the simple sense cannot be used. This will be discussed more detail below. Similar techniques can be used for other transducer technologies. Averaging, for example, can be used to minimize the effects of flickering light in camera based systems.

When an occupant is sitting in the vehicle during normal vehicle operation, the determination of the occupancy state can be substantially improved by using successive observa-

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tions over a period of time. This can either be accomplished by averaging the data prior to insertion into a neural network, or alternately the decision of the neural network can be averaged. This is known as the categorization phase of the process. During categorization the occupancy state of the vehicle is determined. Is the vehicle occupied by the forward facing human, an empty seat, a rear facing child seat, or an out-of-position human? Typically many seconds of data can be accumulated to make the categorization decision.

When a driver senses an impending crash, on the other hand, lie or she will typically slam on the brakes to try to slow vehicle prior to impact. If an occupant is unbelted, he or she will begin moving toward the airbag during this panic braking. For the purposes of determining the position of the occupant, there is not sufficient time to average data as in the case of categorization. Nevertheless, there is information in data from previous vectors that can be used to partially correct errors in current vectors, which may be caused by thermal effects, for example.

One method is to determine the location of the occupant using the neural network based on previous training. The motion of the occupant can then be compared to a maximum likelihood position based on the position estimate of the occupant at previous vectors. Thus, for example, perhaps the existence of thermal gradients in the vehicle caused an error in the current vector leading to a calculation that the occupant has moved 12 inches since the previous vector. Since this could be a physically impossible move during ten milliseconds, the measured position of the occupant can be corrected based on his previous positions and known velocity. Naturally, if an accelerometer is present in the vehicle and if the acceleration data is available for this calculation, a much higher accuracy prediction can be made. Thus, there is information in the data in previous vectors as well as in the positions of the occupant determined from the latest data that can be used to correct erroneous data in the current vector and, therefore, in a manner not too dissimilar from the averaging method for categorization, the position accuracy of the occupant can be known with higher accuracy.

Returning to the placement of ultrasonic transducers for the example of ultrasonic occupant position sensor system, as to the more novel features of the invention for the placement of ultrasonic transducers, this application discloses (1) the application of two sensors to single-axis monitoring of target volumes; (2) the method of locating two sensors spanning a target volume to sense object positions, that is, transducers are mounted along the sensing axis beyond the objects to be sensed; (3) the method of orientation of the sensor axis for optimal target discrimination parallel to the axis of separation of distinguishing target features; and (4) the method of defining the head and shoulders and supporting surfaces as defining humans for rear facing child seat detection and forward facing human detection.

A similar set of observations is available for the use of electromagnetic, capacitive, electric field or other sensors. Such rules however must take into account that some of such sensors typically are more accurate in measuring lateral and vertical dimensions relative to the sensor than distances perpendicular to the sensor. This is particularly the case for CMOS and CCD based transducers.

Considerable work is ongoing to improve the resolution of the ultrasonic transducers. To take advantage of higher resolution transducers, more, closer together data points should be obtained. This means that after the envelope has been extracted from the returned signals, the sampling rate should be increased from approximately 1000 samples per second to perhaps 2000 samples per second or even higher. By doubling or tripling the amount data required to be analyzed, the system which is mounted on the vehicle will

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require greater computational power. This results in a more expensive electronic system. Not all of the data is of equal importance, however. The position of the occupant in the normal seating position does not need to be known with great accuracy whereas as that occupant is moving toward the keep out zone boundary during pre-crash braking, the spatial accuracy requirements become more important. Fortunately, the neural network algorithm generating system has the capability of indicating to the system designer the relative value of each of the data points used by the neural network. Thus, as many as, for example, 500 data points per vector may be collected and fed to the neural network during the training stage and, after careful pruning, the final number of data points to be used by the vehicle mounted system may be reduced to 150, for example. This technique of using the neural network algorithm-generating program to prime the input data is an important teaching of the present invention. By this method, the advantages of higher resolution transducers can be optimally used without increasing the cost of the electronic vehicle mounted circuits. Also, once the neural network has determined the spacing of the data points, this can be fine-tuned, for example, by acquiring more data points at the edge of the keep out zone as compared to positions well into the safe zone. The initial technique is done by collecting the full 500 data points, for example, while in the system installed in the vehicle the data digitization spacing can be determined by hardware or software so that only the required data is acquired.

The technique that was described above for the determination of the location of an occupant during panic or braking pre-crash situations involved the use of a modular neural network. In that case, one neural network was used to determine the occupancy state of the vehicle and a second neural network was used to determine the location of the occupant within the vehicle. The method of designing a system utilizing multiple neural networks is a key teaching of the present invention. When this idea is generalized, many potential combinations of multiple neural network architectures become possible. Some of these will now be discussed.

One of the earliest attempts to use multiple neural networks was to combine different networks trained differently but on substantially the same data under the theory that the errors which affect the accuracy of one network would be independent of the errors which affect the accuracy of another network. For example, for a system containing four ultrasonic transducers, four neural networks could be trained each using a different subset of the four transducer data. Thus, if the transducers are arbitrarily labeled A, B, C and D then the first neural network would be trained on data from A, B and C. The second neural network would be trained on data from B, C, and D etc. This technique has not met with a significant success since it is an attempt to mask errors in the data rather than to eliminate them. Nevertheless, such a system does perform marginally better in some situations compared to a single network using data from all four transducers. The penalty for using such a system is that the computational time is increased by approximately a factor of three. This significantly affects the cost of the system installed in a vehicle.

An alternate method of obtaining some of the advantages of the parallel neural network architecture described above, is to form a single neural network but where the nodes of one or more of the hidden layers are not all connected to all of the input nodes. Alternately, if the second hidden layer is chosen, all of the nodes from the previous hidden layer are not connected to all of the nodes of the subsequent layer. The alternate groups of hidden layer nodes can then be fed to different output nodes and the results of the output nodes combined, either through a neural network training process into a single decision or a voting process. This latter approach retains most of the advantages of the parallel



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neural network while substantially reducing the computational complexity.

The fundamental problem with parallel networks is that they focus on achieving reliability or accuracy by redundancy rather than by improving the neural network architecture itself or the quality of the data being used. They also increase the cost of the final vehicle installed systems. Alternately, modular neural networks improve the accuracy of the system by dividing up the tasks. For example, if a system is to be designed to determine the type of tree or the type of animal in a particular scene, the modular approach would be to first determine whether the object of interest is an animal or a tree and then use separate neural networks to determine type of tree and the type of animal. When a human looks at a tree he is not ask himself is that a tiger or a monkey. Modular neural network systems are efficient since once the categorization decision is made, the seat is occupied by forward facing human, for example, the location of that object can be determined more accurately and without requiring increased computational resources

Another example where modular neural networks have proven valuable is to provide a means for separating "normal" from "special cases". It has been found that in some cases, the vast majority of the data falls into what might be termed "normal" cases that are easily identified with a neural network. The balance of the cases cause the neural network considerable difficulty, however, there are identifiable characteristics of the special cases that permits them to be separated from the normal cases and dealt with separately. Various types of human intelligence rules can be used, in addition to a neural network, to perform this separation including fuzzy logic, statistical filtering using the average class vector of normal cases, the vector standard deviation, and threshold where a fuzzy logic network is used to determine chance of a vector belonging to a certain class. If the chance is below a threshold, the standard neural network is used and if above the special one is used.

Mean-Variance calculations, Fuzzy Logic, Stochastic, and Genetic Algorithm networks, and combinations thereof such as Neuro-Fuzzy systems are other technologies considered in designing an appropriate system. During the process of designing a system to be adapted to a particular vehicle, many different neural network and other pattern recognition architectures are considered including those mentioned above. The particular choice of architecture is frequently determined on a trial and error basis by the system designer in many cases using the combination neural network CAD software from International Scientific Research Inc. Although the parallel architecture system described above has not proven to be in general beneficial, one version of this architecture has shown some promise. It is known that when training a neural network, that as the training process proceeds the accuracy of the decision process improves for the training and independent databases. It is also known that the ability of the network to generalize suffers. That is, when the network is presented with a system which is similar to some case in the database but still with some significant differences, the network may make the proper decision in the early stages of training, but the wrong decisions after the network has become fully trained. This is sometimes called the young network vs. old network dilemma. In some cases, therefore, using an old network in parallel with a young network can retain some of the advantages of both networks, that is, the high accuracy of the old network coupled with the greater generality of the young network. Once again, the choice of any of these particular techniques is part of the process of designing a system to be adapted to a particular vehicle and is a prime subject of this invention. The particular combination of tools used depends on the particular application and the experience of the system designer.

The methods above have been described in connection with the use of ultrasonic transducers. Many of the methods,

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however, are also applicable to optical, radar, capacitive, electric field and other sensing systems and where applicable, this invention is not limited to ultrasonic systems. In particular, an important feature of this invention is the proper placement of three or more separately located receivers such that the system still operates with high reliability if one of the receivers is blocked by some object such as a newspaper. This feature is also applicable to systems using electromagnetic radiation instead of ultrasonic, however the particular locations will differ based on the properties of the particular transducers. Optical sensors based on two-dimensional cameras or other image sensors, for example, are more appropriately placed on the sides of a rectangle surrounding the seat to be monitored rather than at the corners of such a rectangle as is the case with ultrasonic sensors. This is because ultrasonic sensors measure an axial distance from the sensor where the camera is most appropriate for measuring distances up and down and across its field view rather than distances to the object. With the use of electromagnetic radiation and the advances which have recently been made in the field of very low light level sensitivity, it is now possible, in some implementations, to eliminate the transmitters and use background light as the source of illumination along with using a technique such as auto-focusing or stereo vision to obtain the distance from the receiver to the object. Thus, only receivers would be required further reducing the complexity of the system.

Optical sensors can be used to obtain a three dimensional measurement of the object through a variety of methods that use time of flight, modulated light and phase measurement, quantity of light received within a gated window, structured light and triangulation etc. Some of these techniques are discussed in U.S. Pat. No. 6,393,133, which is incorporated herein by reference.

Although implicit in the above discussion, an important feature of this invention which should be emphasized is the method of developing a system having distributed transducer mountings. Other systems which have attempted to solve the rear facing child seat (RFCS) and out-of-position problems have relied on a single transducer mounting location or at most, two transducer mounting locations. Such systems can be easily blinded by a newspaper or by the hand of an occupant, for example, which is imposed between the occupant and the transducers. This problem is almost completely eliminated through the use of three or more transducers which are mounted so that they have distinctly different views of the passenger compartment volume of interest. If the system is adapted using four transducers as illustrated in the distributed system of FIG. 9, for example, the system suffers only a slight reduction in accuracy even if two of the transducers are covered so as to make them inoperable.

It is important in order to obtain the full advantages of the system when a transducer is blocked, that the training and independent databases contains many examples of blocked transducers. If the pattern recognition system, the neural network in this case, has not been trained on a substantial number of blocked transducer cases, it will not do a good job in recognizing such cases later. This is yet another instance where the makeup of the databases is crucial to the success of designing the system that will perform with high reliability in a vehicle and is an important aspect of the instant invention. When camera-based transducers are used, for example, an alternative strategy is to diagnose when a newspaper is blocking a camera, for example. In most cases, a short time blockage is of little consequence since earlier decisions provide the seat occupancy and the decision to enable deployment or suppress deployment of the occupant restraint will not change. For a prolonged blockage, the diagnostic system can provide a warning light indicating to

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the driver that the system is malfunctioning and the deployment decision is again either not changed or changed to the default decision, which is usually to enable deployment.

Other techniques which may or may not be part of the process of designing a system for a particular application include the following:

1. Fuzzy logic. As discussed above, neural networks frequently exhibit the property that when presented with a situation that is totally different from any previously encounter, an irrational decision can result. Frequently when the trained observer looks at input data, certain boundaries to the data become evident and cases that fall outside of those boundaries are indicative of either corrupted data or data from a totally unexpected situation. It is sometimes desirable for the system designer to add rules to handle these cases. These can be fuzzy logic based rules or rules based on human intelligence. One example would be that when certain parts of the data vector fall outside of expected bounds that the system defaults to an airbag enable state.
2. Genetic algorithms. When developing a neural network algorithm for a particular vehicle, there is no guarantee that the best of all possible algorithms has been selected. One method of improving the probability that the best algorithm has been selected is to incorporate some of the principles of genetic algorithms. In one application of this theory, the network architecture and/or the node weights are varied pseudo-randomly to attempt to find other combinations which have higher success rates. The discussion of such genetic algorithms systems appears in the book *Computational Intelligence* referenced above.
- 3 Pre-processing. For military target recognition is common to use the Fourier transform of the data rather than the data itself. This can be especially valuable for categorization as opposed to location of the occupant and the vehicle. When used with a modular network, for example, the Fourier transform of the data may be used for the categorization neural network and the non-transformed data used for the position determination neural network. Recently wavelet transforms have also been considered as a preprocessor.
4. Occupant position determination comparison. Above, under the subject of dynamic out-of-position, it was discussed that the position of the occupant can be used as a filter to determine the quality of the data in a particular vector. This technique can also be used in general as a method to improve the quality of a vector of data based on the previous positions of the occupant. This technique can also be expanded to help differentiate live objects in the vehicle from inanimate objects. For example, a forward facing human will change his position frequently during the travel of the vehicle whereas a box will tend to show considerably less motion. This is also useful, for example, in differentiating a small human from an empty seat. The motion of a seat containing a small human will be significantly different from that of an empty seat even though the particular vector may not show significant differences. That is, a vector formed from the differences from two successive vectors is indicative of motion and thus of an occupant.
5. Blocked transducers. It is sometimes desirable to positively identify a blocked transducer and when such a situation is found to use a different neural network which has only been trained on the subset of unblocked transducers. Such a network, since it has been trained specifically on three transducers, for example, will generally perform more accurately than a network

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which has been trained on four transducers with one of the transducers blocked some of the time. Once a blocked transducer has been identified the occupant can be notified if the condition persists for more than a reasonable time.

6. Other Basic Architectures. The back propagation neural network is a very successful general-purpose network. However, for some applications, there are other neural network architectures that can perform better. If it has been found, for example, that a parallel network as described above results in a significant improvement in the system, then, it is likely that the particular neural network architecture chosen has not been successful in retrieving all of the information that is present in the data. In such a case, an RCE, Stochastic, Logicon Projection, cellular, support vector machine or one of the other approximately 30 types of neural network architectures can be tried to see if the results improve. This parallel network test, therefore, is a valuable tool for determining the degree to which the current neural network is capable of using efficiently the available data.
7. Transducer Geometry. Another technique, which is frequently used in designing a system for a particular vehicle, is to use a neural network to determine the optimum mounting locations, aiming or orientation directions and field angles of transducers. For particularly difficult vehicles, it is sometimes desirable to mount a large number of ultrasonic transducers, for example, and then use the neural network to eliminate those transducers which are least significant. This is similar to the technique described above where all kinds of transducers are combined initially and later pruned.
8. Data quantity. Since it is very easy to take large amounts data and yet large databases require considerably longer training time for a neural network, a test of the variability of the database can be made using a neural network. If, for example, after removing half of the data in the database, the performance of a trained neural network against the validation database does not decrease, then the system designer suspects that the training database contains a large amount of redundant data. Techniques such as similarity analysis can then be used to remove data that is virtually indistinguishable from other data. Since it is important to have a varied database, it is undesirable generally to have duplicate or essentially duplicate vectors in the database since the presence of such vectors can bias the system and drive the system more toward memorization and away from generalization.
9. Environmental factors. An evaluation can be made of the beneficial effects of using varying environmental influences, such as temperature or lighting, during data collection on the accuracy of the system using neural networks along with a technique such as design of experiments.
10. Database makeup. It is generally believed that the training database must be flat, meaning that all of the occupancy states that the neural network must recognize must be approximately equally represented in the training database. Typically, the independent database has approximately the same makeup as the training database. The validation database, on the other hand, typically is represented in a non-flat basis with representative cases from real world experience. Since there is no need for the validation database to be flat, it can include many of the extreme cases as well as being highly biased towards the most common cases. This is the theory that is currently being used to determine the

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makeup of the various databases. The success of this theory continues to be challenged by the addition of new cases to the validation database. When significant failures are discovered in the validation database, the training and independent databases are modified in an attempt to remove the failure.

11. Biasing. All seated state occupancy states are not equally important. The final system must be nearly 100% accurate for forward facing "in-position" humans. Since that will comprise the majority of the real world situations, even a small loss in accuracy here will cause the airbag to be disabled in a situation where it otherwise would be available to protect an occupant. A small decrease in accuracy will thus result in a large increase in deaths and injuries. On the other hand, there are no serious consequences if the airbag is deployed occasionally when the seat is empty. Various techniques are used to bias the data in the database to take this into account. One technique is to give a much higher value to the presence of a forward facing human during the supervised learning process than to an empty seat. Another technique is to include more data for forward facing humans than for empty seats. This, however, can be dangerous as an unbalanced network leads to a loss of generality.
12. Screening. It is important that the loop be closed on data acquisition. That is, the data must be checked at the time the data is acquired to be sure that it is good data. Bad data can happen, for example, because of electrical disturbances on the power line, sources of ultrasound such as nearby welding equipment, or due to human error. If the data remains in the training database, for example, then it will degrade the performance of the network. Several methods exist for eliminating bad data. The most successful method is to take an initial quantity of data, such as 30,000 to 50,000 vectors, and create an interim network. This is normally done anyway as an initial check on the system capabilities prior to engaging in an extensive data collection process. The network can be trained on this data and, as the real training data is acquired, the data can be tested against the neural network created on the initial data set. Any vectors that fail are examined for reasonableness.
13. Vector normalization method. Through extensive research it has been found that the vector should be normalized based on all of the data in the vector, that is have all its data values range from 0 to 1. For particular cases, however, it has been found desirable to apply the normalization process selectively, eliminating or treating differently the data at the early part of the data from each transducer. This is especially the case when there is significant ringing on the transducer or cross talk when a separate send and receive transducer is used. There are times when other vector normalization techniques are required and the neural network system can be used to determine the best vector normalization technique for a particular application.
14. Feature extraction. The success of a neural network system can frequently be aided if additional data is inputted into the network. One example can be the number of 0 data points before the first peak is experienced. Alternately, the exact distance to the first peak can be determined prior to the sampling of the data. Other features can include the number of peaks, the distance between the peaks, the width of the largest peak, the normalization factor, the vector mean or standard deviation, etc. These normalization techniques are frequently used at the end of the adaptation process to slightly increase the accuracy of the system.

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15. Noise. It has been frequently reported in the literature that adding noise to the data that is provided to a neural network can improve the neural network accuracy by leading to better generalization and away from memorization. However, the training of the network in the presence of thermal gradients has been shown to substantially eliminate the need to artificially add noise to the data. Nevertheless, in some cases, improvements have been observed when random arbitrary noise of a rather low level is superimposed on the training data.
16. Photographic recording of the setup. After all of the data has been collected and used to train a neural network, it is common to find a significant number of vectors which, when analyzed by the neural network, give a weak or wrong decision. These vectors must be carefully studied especially in comparison with adjacent vectors to see if there is an identifiable cause for the weak or wrong decision. Perhaps the occupant was on the borderline of the keep out zone and strayed into the keep out zone during a particular data collection event. For this reason, it is desirable to photograph each setup simultaneous with the collection of the data. This can be done using one or more cameras mounted in positions where they can have a good view of the seat occupancy. Sometimes several cameras are necessary to minimize the effects of blockage by a newspaper, for example. Having the photographic record of the data setup is also useful when similar results are obtained when the vehicle is subjected to road testing. During road testing, one or more cameras should also be present and the test engineer is required to initiate data collection whenever the system does not provide the correct response. The vector and the photograph of this real world test can later be compared to similar setups in the laboratory to see whether there is data that was missed in deriving the matrix of vehicle setups for training the vehicle.
17. Automation. When collecting data in the vehicle it is desirable to automate the motion of the vehicle seat, seatback, windows, visors etc. in this manner the positions of these items can be controlled and distributed as desired by the system designer. This minimizes the possibility of taking too much data at one configuration and thereby unbalancing the network.
18. Automatic setup parameter recording. To achieve an accurate data set, the key parameters of the setup should be recorded automatically. These include the temperatures at various positions inside the vehicle, the position of the vehicle seat, and seatback, the position of the headrest, visor and windows and, where possible, the position of the vehicle occupants. The automatic recordation of these parameters minimizes the effects of human errors.
19. Laser Pointers. During the initial data collection with full horns mounted on the surface of the passenger compartment, care must be exercised so that the transducers are not accidentally moved during the data collection process. In order to check for this possibility, a small laser diode is incorporated into each transducer holder. The laser is aimed so that it illuminates some other surface of the passenger compartment at a known location. Prior to each data taking session, each of the transducer aiming points is checked.
20. Multi-frequency transducer placement. When data is collected for dynamic out-of-position, each of the ultrasonic transducers must operate at a different frequency so that all transducers can transmit simultaneously. By this method data can be collected every 10 milliseconds, which is sufficiently fast to approximately track the motion of an occupant during pre-



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crash braking prior to an impact. A problem arises in the spacing of the frequencies between the different transducers. If the spacing is too close, it becomes very difficult to separate the signals from different transducers and it also affects the sampling rate of the transducer data and thus the resolution of the transducers. If an ultrasonic transducer operates at a frequency much below about 35 kHz, it can be sensed by dogs and other animals. If the transducer operates at a frequency much above 70 kHz, it is very difficult to make the open type of ultrasonic transducer, which produces the highest sound pressure. If the multiple frequency system is used for both the driver and passenger-side, as many as eight separate frequencies are required. In order to find eight frequencies between 35 and 70 kHz, a frequency spacing of 5 kHz is required. In order to use conventional electronic filters and to provide sufficient spacing to permit the desired resolution at the keep out zone border, a 10 kHz spacing is desired. These incompatible requirements can be solved through a careful judicious placement of the transducers such that transducers that are within 5 kHz of each other are placed in such a manner that there is no direct path between the transducers and any indirect path is sufficiently long so that it can be filtered temporally. An example of such an arrangement is shown on FIG. 11. For this example, the transducers operate at the following frequencies A 65 kHz, B 55 kHz, C 35 kHz, D 45 kHz, E 50 kHz, F 40 kHz, G 60 kHz, H 70 kHz. Actually, other arrangements adhering to the principle described above would also work.

21. Use of a PC in data collection. When collecting data for the training, independent, and validation databases, it is frequently desirable to test the data using various screening techniques and to display the data on a monitor. Thus, during data collection the process is usually monitored using a desktop PC for data taken in the laboratory and a laptop PC for data taken on the road.
22. Use of referencing markers and gages. In addition to and sometimes as a substitution for, the automatic recording of the positions of the seats, seatback, windows etc. as described above, a variety of visual markings and gages are frequently used. This includes markings to show the angular position of the seatback, the location of the seat on the seat track, the openness of the window, etc. Also in those cases where automatic tracking of the occupant is not implemented, visual markings are placed such that a technician can observe that the test occupant remains within the required zone for the particular data taking exercise. Sometimes, a laser diode is used to create a visual line in the space that represents the boundary of the keep out zone or other desired zone boundary.
23. Subtracting out data that represents reflections from known seat parts or other vehicle components. This is particularly useful if the seat track and seatback recline positions are known.
24. Improved identification and tracking can sometimes be obtained if the object can be centered or otherwise located in a particular part of the neural network in a manner similar to the way the human eye centers an object to be examined in its field of view.
25. Continuous tracking of the object in place of a zone-based system also improves the operation of the pattern recognition system since discontinuities are frequently difficult for the pattern recognition system such as a neural network to handle. In this case, the location of the occupant relative to the airbag cover, for example, would be determined and then a calculation

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as to what zone the object is located in can be determined and the airbag deployment decision made (suppression, depowered, delayed, deployment). This also permits a different suppression zone to be used for different sized occupants further improving the matching of the airbag deployment to the occupant.

It is important to realize that the adaptation process described herein applies to any combination of transducers that provide information about the vehicle occupancy. These include weight sensors, capacitive sensors, electric field sensors, inductive sensors, moisture sensors, chemical sensors, ultrasonic, optic, infrared, radar among others. The adaptation process begins with a selection of candidate transducers for a particular vehicle model. This selection is based on such considerations as cost, alternate uses of the system other than occupant sensing, vehicle interior passenger compartment geometry, desired accuracy and reliability, vehicle aesthetics, vehicle manufacturer preferences, and others. Once a candidate set of transducers has been chosen, these transducers are mounted in the test vehicle according to the teachings of this invention. The vehicle is then subjected to an extensive data collection process wherein various objects are placed in the vehicle at various locations as described below and an initial data set is collected. A pattern recognition system is then developed using the acquired data and an accuracy assessment is made. Further studies are made to determine which, if any, of the transducers can be eliminated from the design. In general the design process begins with a surplus of sensors plus an objective as to how many sensors are to be in the final vehicle installation. The adaptation process can determine which of the transducers are most important and which are least important and the least important transducers can be eliminated to reduce system cost and complexity.

Thus disclosed above is a system for determining the occupancy state of a seat which comprises a plurality of transducers arranged in the vehicle, each transducers providing data relating to the occupancy state of the seat, and processor means or a processing unit (e.g., a microprocessor) coupled to the transducers for receiving the data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. The processor means comprise a combination neural network algorithm created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from data from the transducers while the seat is in that occupancy state. The combination neural network algorithm produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers. The algorithm may be a pattern recognition algorithm or neural network algorithm generated by a combination neural network algorithm-generating program.

The processor means may be arranged to accept only a separate stream of data from each transducer such that the stream of data from each transducer is passed to the processor means without combining with another stream of data. Further, the processor means may be arranged to process each separate stream of data independent of the processing of the other streams of data.

The transducers may be selected from a wide variety of different sensors, all of which are affected by the occupancy state of the seat. That is, different combinations of known sensors can be utilized in the many variations of the invention. For example, the sensors used in the invention may include a weight sensor arranged in the seat, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, a seat position sensor for detecting the position of the seat relative to a fixed reference point in the vehicle, a

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heartbeat sensor for sensing a heartbeat of an occupying item of the seat, a capacitive sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensors, an inductive sensor, a motion sensor, a chemical sensor such as a carbon dioxide sensor and a radar sensor. The same type of sensor could also be used, preferably situated in a different location, but possibly in the same location for redundancy purposes. For example, the system may include a plurality of weight sensors, each measuring the weight applied onto the seat at a different location. Such weight sensors may include a weight sensor, such as a strain gage or bladder, arranged to measure displacement of a surface of a seat portion of the seat and/or a strain, force or pressure gage arranged to measure displacement of the entire seat. In the latter case, the seat includes a support structure for supporting the seat above a floor of a passenger compartment of the vehicle whereby the strain gage can be attached to the support structure.

In some embodiments, the transducers include a plurality of electromagnetic wave sensors capable of receiving waves at least from a space above the seat, each electromagnetic wave sensor being arranged at a different location. Other wave or field sensors, such as capacitive or electric field sensors, can also be used.

In other embodiments, the transducers include at least two ultrasonic sensors capable of receiving waves at least from a space above the seat bottom, each ultrasonic sensor being arranged at a different location. For example, one sensor is arranged on a ceiling of the vehicle and the other is arranged at a different location in the vehicle, preferably so that an axis connecting the sensors is substantially parallel to a second axis traversing a volume in the vehicle above the seat. The second sensor may be arranged on a dashboard or instrument panel of the vehicle. A third ultrasonic sensor can be arranged on an interior side surface of the passenger compartment while a fourth can be arranged on or adjacent an interior side surface of the passenger compartment. The ultrasonic sensors are capable of transmitting waves at least into the space above the seat. Further, the ultrasonic sensors are preferably aimed such that the ultrasonic fields generated thereby cover a substantial portion of the volume surrounding the seat. Horns or grills may be provided for adjusting the transducer field angles of the ultrasonic sensors to reduce reflections off of fixed surfaces within the vehicle or otherwise control the shape of the ultrasonic field. Other types of sensors can of course be placed at the same or other locations.

The actual location of the sensors can be determined by placing a significant number of sensors in the vehicle and removing those sensors which prove analytically to be redundant

The ultrasonic sensors can have different transmitting and receiving frequencies and be arranged in the vehicle such that sensors having adjacent transmitting and receiving frequencies are not within a direct ultrasonic field of each other.

Once the occupancy state of the seat (or seats) in the vehicle is known, this information can be used to control or affect the operation of a significant number of vehicular systems, components and devices. That is, the systems, components and devices in the vehicle would be controlled in consideration of the occupancy of the seat(s) in the vehicle, possibly to optimize operation of the same. Thus, the vehicle includes control means coupled to the processor means for controlling a component or device in the vehicle in consideration of the output indicative of the current occupancy state of the seat obtained from the processor means. The component or device can be an airbag system including at least one deployable airbag whereby the deployment of the airbag is suppressed, e.g., if the seat is occupied by a rear-facing child seat, or otherwise the parameters of the deployment are controlled.

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Another the system for determining the occupancy state of a seat in a vehicle includes a plurality of transducers arranged in the vehicle, each providing data relating to the occupancy state of the seat, and processor means coupled to the transducers for receiving only a separate stream of data from each transducer (such that the stream of data from each transducer is passed to the processor means without combining with another stream of data) and processing the streams of data to obtain an output indicative of the current occupancy state of the seat. The processor means comprise an algorithm created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from separate streams of data, each only from one transducer, while the seat is in that occupancy state. The algorithm produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from separate streams of data, each only from one transducer. The processor means preferably process each separate stream of data independent of the processing of the other streams of data.

In yet another embodiment of the invention, the system for determining the occupancy state of a seat in a vehicle includes a plurality of transducers including at least two wave-receiving or field transducers arranged in the vehicle, each providing data relating to the occupancy state of the seat. One wave-receiving or field transducer is arranged on or adjacent to a ceiling of the vehicle and a second wave-receiving or field transducer is arranged at a different location in the vehicle such that an axis connecting these transducers is substantially parallel to a longitudinal axis of the vehicle, substantially parallel to a transverse axis of the vehicle or passes through a volume above the seat. A processor is coupled to the transducers for receiving data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. The processor comprises an algorithm which produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers.

In still another embodiment of the invention, the system includes a plurality of transducers arranged in the vehicle, each providing data relating to the occupancy state of the seat, and which include wave-receiving transducers and/or non-wave-receiving transducers. The system also includes processor means coupled to the transducers for receiving the data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. The processor means comprising an algorithm created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from data from the transducers while the seat is in that occupancy state. The algorithm produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers.

Although several preferred methods are illustrated and described above, there are other possible combinations using different sensors located at different positions within the automobile passenger compartment which measure either the same or different characteristics of an occupying object to accomplish the same or similar goals as those described herein. There are also numerous additional applications in addition to those described above including, but not limited to, monitoring the driver seat, the center seat or the rear seat of the vehicle or for controlling other vehicle systems in addition to the airbag system. This invention is not limited to the above embodiments and should be determined by the following claims.

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**Appendix 1****Analysis of Neural Network Training and Data Preprocessing Methods - An Example****1. Introduction**

5 The Artificial Neural Network that forms the “brains” of the Occupant Spatial Sensor needs to be trained to recognize airbag enable and disable patterns. The most important part of this training is the data that is collected in the vehicle, which provides the patterns corresponding to these respective configurations. Manipulation of this data (such as filtering) is appropriate if this enhances the information contained in the data. Important too, are the basic network architecture and training methods applied, as these two determine the learning and generalization capabilities of the neural network. The ultimate test for all methods and filters is their effect on the network performance against real world situations.

10 The Occupant Spatial Sensor (OSS) uses an artificial neural network (ANN) to recognize patterns that it has been trained to identify as either airbag enable or airbag disable conditions. The pattern is obtained from four ultrasonic transducers that cover the front passenger seating area. This pattern consists of the ultrasonic echoes from the objects in the passenger seat area. The signal from each of the four transducers consists of the electrical image of the return echoes, which is processed by the electronics. The electronic processing comprises amplification (logarithmic compression), rectification, and demodulation (band pass filtering), followed by discretization (sampling) and digitization of the signal. The only software processing required, before this signal can be fed into the artificial neural network, is normalization (i.e. mapping the input to numbers between 0 and 1). Although this is a fair amount of processing, the resulting signal is still considered “raw”, because all information is treated equally.

20 It is possible to apply one or more software preprocessing filters to the raw signal before it is fed into the artificial neural network. The purpose of such filters is to enhance the useful information going into the ANN, in order to increase the system performance. This document describes several preprocessing filters that were applied to the ANN training of a particular vehicle.

**25 2. Data Description**

The performance of the artificial neural network is dependent on the data that is used to train the network. The amount of data and the distribution of the data within the realm of possibilities are known to have a large effect on the ability of the network to recognize patterns and to generalize. Data for the OSS is made up of vectors. Each vector is a combination of the useful parts of the signals collected from four ultrasonic transducers. A typical vector could comprise on the order of 100 data points, each representing the (time displaced) echo level as recorded by the ultrasonic transducers.

30 Three different sets of data are collected. The first set, the training data, contains the patterns that the ANN is being trained on to recognize as either an airbag deploy or non-deploy scenario. The second set is the independent test data. This set is used during the network training to direct the optimization of the network weights. The third set is the validation (or real world) data. This set is used to quantify the success rate (or performance) of the finalized artificial neural network.

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FIG. 26 shows the main characteristics of these three data sets, as collected for the vehicle. Three numbers characterize the sets. The number of configurations characterizes how many different subjects and objects were used. The number of setups is the product of the number of configurations and the number of vehicle interior variations (seat position and recline, roof and window state, etc.) performed for each configuration. The total number of vectors is then made up of the product of the number of setups and the number of patterns collected while the subject or object moves within the passenger volume.

#### 1.1 Training Data Set Characteristics

The training data set can be split up in various ways into subsets that show the distribution of the data. FIG. 27 shows the distribution of the training set amongst three classes of passenger seat occupancy: Empty Seat, Human Occupant, and Child Seat. All human occupants were adults of various sizes. No children were part of the training data set other than those seated in Forward Facing Child Seats. FIG. 28 shows a further breakup of the Child Seats into Forward Facing Child Seats, Rearward Facing Child Seats, Rearward Facing Infant Seats, and out-of-position Forward Facing Child Seats. FIG. 29 shows a different type of distribution; one based on the environmental conditions inside the vehicle.

#### 1.2 Independent Test Data Characteristics

The independent test data is created using the same configurations, subjects, objects, and conditions as used for the training data set. Its makeup and distributions are therefore the same as those of the training data set.

#### 1.3 Validation Data Characteristics

The distribution of the validation data set into its main subsets is shown in FIG. 30. This distribution is close to that of the training data set. However, the human occupants comprised both children (12 % of total) as well as adults (27 % of total). FIG. 31 shows the distribution of human subjects. Contrary to the training and independent test data sets, data was collected on children ages 3 and 6 that were *not* seated in a child restraint of any kind. FIG. 32 shows the distribution of the child seats used. On the other hand, no data was collected on Forward Facing Child Seats that were out-of-position. The child and infant seats used in this data set are different from those used in the training and independent test data sets. The validation data was collected with varying environmental conditions as shown in FIG. 33.

### 3. Network Training

The baseline network consisted of a four layer back-propagation network with 117 input layer nodes, 20 and 7 nodes respectively in the two hidden layers, and 1 output layer node. The input layer is made up of inputs from four ultrasonic transducers. These were located in the vehicle on the rear quarter panel (A), the A-pillar (B), and the over-head console (C, H). FIG. 34 shows the number of points, taken from each of these channels that make up one vector.

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The artificial neural network is implemented using the NeuralWorks Professional II/Plus software. The method used for training the decision mathematical model was back-propagation with Extended Delta-Bar-Delta learning rule and sigmoid transfer function. The Extended DBD paradigm uses past values of the gradient to infer the local curvature of the error surface. This leads to a learning rule in which every connection has a different learning rate and a different momentum term, both of which are automatically calculated.

The network was trained using the above-described training and independent test data sets. An optimum (against the independent test set) was found after 3,675,000 training cycles. Each training cycle uses 30 vectors (known as the epoch), randomly chosen from the 650,000 available training set vectors. FIG. 35 shows the performance of the baseline network.

The network performance has been further analyzed by investigating the success rates against subsets of the independent test set. The success rate against the airbag enable conditions at 94.6% is virtually equal to that against the airbag disable conditions at 94.4%. FIG. 36 shows the success rates for the various occupancy subsets. FIG. 37 shows the success rates for the environmental conditions subsets. Although the distribution of this data was not entirely balanced throughout the matrix, it can be concluded that the system performance is not significantly degraded by heat sources.

### 3.1 Normalization

Normalization is used to scale the real world data range into a range acceptable for the network training. The NeuralWorks software requires the use of a scaling factor to bring the input data into a range of 0 to 1, inclusive. Several normalization methods have been explored for their effect on the system performance.

The real world data consists of 12 bit, digitized signals with values between 0 and 4095. FIG. 38 shows a typical raw signal. A raw vector consists of combined sections of four signals.

Three methods of normalization of the individual vectors have been investigated:

- a. Normalization using the highest and lowest value of the entire vector (baseline).
- b. Normalization of the transducer channels that make up the vector, individually. This method uses the highest and lowest values of each channel.
- c. Normalization with a fixed range ([0,4095]).

The results of the normalization study are summarized in FIG. 39.

A higher performance results from normalizing across the entire vector versus normalizing per channel. This can be explained from the fact that the baseline method retains the information contained in the relative strength of the signal from one transducer compared to another. This information is lost when using the second method.

Normalization using a fixed range retains the information contained in the relative strength of one vector compared to the next. From this it could be expected that the performance of the network trained with fixed range



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normalization would increase over that of the baseline method. However, without normalization, the input range is, as a rule, not from zero to the maximum value (see FIG. 39). The absolute value of the data at the input layer affects the network weight adjustment (see equations [1] and [2]). During network training, vectors with a smaller input range will affect the weights calculated for each processing element (neuron) differently than vectors that do span the full range.

$$\Delta w_{ij}^{[s]} = lcoef \cdot e_j^{[s]} \cdot x_i^{[s-1]} \quad [1]$$

$$e_j^{[s]} = x_j^{[s]} \cdot (1.0 - x_j^{[s]}) \cdot \Delta_k (e_k^{[s+1]} \cdot w_{kj}^{[s+1]}) \quad [2]$$

$\Delta w_{ij}^{[s]}$  is the change in the network weights; *lcoef* is the learning coefficient;  $e_j^{[s]}$  is the local error at neuron j in layer s;  $x_i^{[s]}$  is the current output state of neuron i in layer s.

Variations in the highest and lowest values in the input layer, therefore, have a negative effect on the training of the network. This is reflected in a lower performance against the validation data set.

A secondary effect of normalization is that it increases the resolution of the signal by stretching it out over the full range of 0 to 1, inclusive. As the network predominantly learns from higher peaks in the signal, this results in better generalization capabilities and therefore in a higher performance.

It must be concluded that the effects of the fixed range of input values and the increased resolution resulting from the baseline normalization method have a stronger effect on the network training than retaining the information contained in the relative vector strength.

### 3.2 Low Threshold Filters

Not all information contained in the raw signals can be considered useful for network training. Low amplitude echoes are received back from objects on the outskirts of the ultrasonic field that should not be included in the training data. Moreover, low amplitude noise, from various sources, is contained within the signal. This noise shows up strongest where the signal is weak. By using a low threshold filter, the signal to noise ratio of the vectors can be improved before they are used for network training.

Three cutoff levels were used: 5%, 10%, and 20% of the signal maximum value (4095). The method used, brings the values below the threshold up to the threshold level. Subsequent vector normalization (baseline method) stretches the signal to the full range of [0,1].

The results of the low threshold filter study are summarized in FIG. 40.

The performance of the networks trained with 5% and 10% threshold filter is similar to that of the baseline network. A small performance degradation is observed for the network trained with a 20% threshold filter. From this it is concluded that the noise level is sufficiently low to not affect the network training. At the same time it can be concluded that the lower 10% of the signal can be discarded without affecting the network performance.

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This allows the definition of demarcation lines on the outskirts of the ultrasonic field where the signal is equal to 10% of the maximum field strength.

#### 4. Network Types

5 The baseline network is a back-propagation type network. Back-propagation is a general-purpose network paradigm that has been successfully used for prediction, classification, system modeling, and filtering as well as many other general types of problems. Back propagation learns by calculating an error between desired and actual output and propagating this error information back to each node in the network. This back-propagated error is used to drive the learning at each node. Some of the advantages of a back-propagation network are that it attempts to minimize the global error and that it can provide a very compact distributed representation of complex data sets. 10 Some of the disadvantages are its slow learning and the irregular boundaries and unexpected classification regions due to the distributed nature of the network and the use of a transfer functions that is unbounded. Some of these disadvantages can be overcome by using a modified back-propagation method such as the Extended Delta-Bar-Delta paradigm. The EDBD algorithm automatically calculates the learning rate and momentum for each connection in the network, which facilitates optimization of the network training. 15

Many other network architectures exist that have different characteristics than the baseline network. One of these is the Logicon Projection Network. This type of network combines the advantages of closed boundary networks with those of open boundary networks (to which the back-propagation network belongs). Closed boundary networks are fast learning because they can immediately place prototypes at the input data points and match all input data to these prototypes. Open boundary networks, on the other hand, have the capability to minimize the output error through gradient decent. 20

#### 5. Conclusions

The baseline artificial neural network trained to a success rate of 92.7% against the validation data set. This network has a four-layer back-propagation architecture and uses the Extended Delta-Bar-Delta learning rule and sigmoid transfer function. Pre-processing comprised vector normalization while post-processing comprised a "five consistent decision" filter. 25

The objects and subjects used for the independent test data were the same as those used for the training data. This may have negatively affected the network's classification generalization abilities.

The spatial distribution of the independent test data was as wide as that of the training data. This has resulted in a network that can generalize across a large spatial volume. A higher performance across a smaller volume, located immediately around the peak of the normal distribution, combined with a lower performance on the outskirts of the distribution curve, might be preferable. 30

To achieve this, the distribution of the independent test set needs to be a reflection of the normal distribution for the system (a.k.a. native population).

35 Modifying the pre-processing method or applying additional pre-processing methods did not show a significant improvement of the performance over that of the baseline network. The baseline normalization method

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gave the best results as it improves the learning by keeping the input values in a fixed range and increases the signal resolution. The lower threshold study showed that the network learns from the larger peaks in the echo pattern. Pre-processing techniques should be aimed at increasing the signal resolution to bring out these peaks.

5 A further study could be performed to investigate combining a lower threshold with fixed range normalization, using a range less than full scale. This would force each vector to include at least one point at the lower threshold value and one value in saturation, effectively forcing each vector into a fixed range that can be mapped between 0 and 1, inclusive. This would have the positive effects associated with the baseline normalization, while retaining the information contained in the relative vector strength. Raw vectors points that, as a result of the scaling, would fall outside the range of 0 to 1 would then be mapped to 0 and 1 respectively.

10 Post-processing should be used to enhance the network recognition ability with a memory function. The possibilities for such are currently frustrated by the necessity of one network performing both object classification as well as spatial locating functions. Performing the spatial locating function requires flexibility to rapidly update the system status. Object classification, on the other hand, benefits from decision rigidity to nullify the effect of an occasional pattern that is incorrectly classified by the network.

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**Appendix 2****Process for training an OPS system DOOP network for a specific vehicle**

1. Define customer requirements and deliverables
  - 5 1.1. Number of zones
  - 1.2. Number of outputs
  - 1.3. At risk zone definition
  - 1.4. Decision definition i.e. empty seat at risk, safe seating, or not critical and undetermined
  - 1.5. Determine speed of DOOP decision
- 10 2. Develop PERT chart for the program
3. Determine viable locations for the transducer mounts
  - 3.1. Manufacturability
  - 3.2. Repeatability
  - 3.3. Exposure (not able to damage during vehicle life)
- 15 4. Evaluate location of mount logistics
  - 4.1. Field dimensions
  - 4.2. Multipath reflections
  - 4.3. Transducer Aim
  - 4.4. Obstructions / Unwanted data
  - 20 4.5. Objective of view
  - 4.6. Primary DOOP transducers requirements
5. Develop documentation logs for the program (vehicle books)
6. Determine vehicle training variables
  - 6.1. Seat track stops
  - 25 6.2. Steering wheel stops
  - 6.3. Seat back angles
  - 6.4. DOOP transducer blockage during crash
  - 6.5. Etc...
7. Determine and mark at risk zone in vehicle
- 30 8. Evaluate location physical impediments
  - 8.1. Room to mount / hide transducers
  - 8.2. Sufficient hard mounting surfaces
  - 8.3. Obstructions
9. Develop matrix for training, independent, validation, and DOOP data sets
- 35 10. Determine necessary equipment needed for data collection
  - 10.1. Child / booster / infant seats

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- 10.2. Maps / razors / makcup
- 10.3. Etc...
- 11. Schedule sled tests for initial and final DOOP networks
- 12. Design test buck for DOOP
- 5 13. Design test dummy for DOOP testing
- 14. Purchase any necessary variables
  - 14.1. Child / booster / infant seats
  - 14.2. Maps / razors / makeup
  - 14.3. Etc...
- 10 15. Develop automated controls of vehicle accessories
  - 15.1. Automatic seat control for variable empty seat
  - 15.2. Automatic seat back angle control for variable empty seat
  - 15.3. Automatic window control for variable empty seat
  - 15.4. Etc...
- 15 16. Acquire equipment to build automated controls
- 17. Build & install automated controls of vehicle variables
- 18. Install data collection aides
  - 18.1. Thermometers
  - 18.2. Seat track gauge
  - 20 18.3. Seat angle gauge
  - 18.4. Etc...
- 19. Install switched and fused wiring for:
  - 19.1. Transducer pairs
  - 19.2. Lasers
  - 25 19.3. Decision Indicator Lights
  - 19.4. System box
  - 19.5. Monitor
  - 19.6. Power automated control items
  - 19.7. Thermometers, potentiometers
  - 30 19.8. DOOP occupant ranging device
  - 19.9. DOOP ranging indicator
  - 19.10. Etc...
- 20. Write DOOP operating software for OPS system box
- 21. Validate DOOP operating software for OPS
- 35 22. Build OPS system control box for the vehicle with special DOOP operating software
- 23. Validate & document system control box

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- 24. Write vehicle specific DOOP data collection software (pollbin)
- 25. Write vehicle specific DOOP data evaluation program (picgraph)
- 26. Evaluate DOOP data collection software
- 27. Evaluate DOOP data evaluation software
- 5 28. Load DOOP data collection software on OPS system box and validate
- 29. Load DOOP data evaluation software on OPS system box and validate
- 30. Train technicians on DOOP data collection techniques and use of data collection software
- 31. Design prototype mounts based on known transducer variables
- 32. Prototype mounts
- 10 33. Pre-build mounts
  - 33.1. Install transducers in mounts
  - 33.2. Optimize to eliminate crosstalk
  - 33.3. Obtain desired field
  - 33.4. Validate performance of DOOP requirements for mounts
- 15 34. Document mounts
  - 34.1. Polar plots of fields
  - 34.2. Drawings with all mount dimensions
  - 34.3. Drawings of transducer location in the mount
- 35. Install mounts in the vehicle
- 20 36. Map fields in the vehicle using ATI designed apparatus and specification
- 37. Map performance in the vehicle of the DOOP transducer assembly
- 38. Determine sensor volume
- 39. Document vehicle mounted transducers and fields
  - 39.1. Mapping per ATI specification
- 25 39.2. Photographs of all fields
- 39.3. Drawing and dimensions of installed mounts
- 39.4. Document sensor volume
- 39.5. Drawing and dimensions of aim & field
- 40. Using data collection software and OPS system box collect initial 16 sheets of training, independent, and
- 30 validation data
- 41. Determine initial conditions for training the ANN
  - 41.1. Normalization method
  - 41.2. Training via back propagation or ?
  - 41.3. Weights
- 35 41.4. Etc...
- 42. Pre-process data



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- 43. Train an ANN on above data
- 44. Develop post processing strategy if necessary
- 45. Develop post processing software
- 46. Evaluate ANN with validation data and in vehicle analysis
- 5 47. Perform sled tests to confirm initial DOOP results
- 48. Document DOOP testing results and performance
- 49. Rework mounts and repeat steps 31 through 48 if necessary
- 50. Meet with customer and review program
- 51. Develop strategy for customer directed outputs
- 10 51.1. Develop strategy for final ANN multiple decision networks if necessary
- 51.2. Develop strategy for final ANN multiple layer networks if necessary
- 51.3. Develop strategy for DOOP layer / network
- 52. Design daily calibration jig
- 53. Build daily calibration jig
- 15 54. Develop daily calibration test
- 55. Document daily calibration test procedure & jig
- 56. Collect daily calibration tests
- 57. Document daily calibration test results
- 58. Rework vehicle data collection markings for customer directed outputs
- 20 58.1. Multiple zone identifiers for data collection
- 59. Schedule subjects for all data sets
- 60. Train subjects for data collection procedures
- 61. Using DOOP data collection software and OPS system box collect initial 16 sheets of training, independent, and validation data
- 25 62. Collect total amount of vectors deemed necessary by program directives, amount will vary as outputs and complexity of ANN varies
- 63. Determine initial conditions for training the ANN
  - 63.1. Normalization method
  - 63.2. Training via back propagation or ?
- 30 63.3. Weights
- 63.4. Etc...
- 64. Pre-process data
- 65. Train an ANN on above data
- 66. Develop post processing strategy
- 35 66.1. Weighting
- 66.2. Averaging

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We claim:

1. A method for controlling an occupant protection device in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant in a seat to be protected by the occupant protection device;

classifying the type of occupant based on the acquired data;

when the occupant is classified as an empty seat or a rear-facing child seat, disabling or adjusting deployment of the occupant protection device; otherwise classifying the size of the occupant based on the acquired data;

determining the position of the occupant by means of one of a plurality of algorithms selected based on the classified size of the occupant using the acquired data, each of the algorithms being applicable for a specific size of occupant, and

disabling or adjusting deployment of the occupant protection device when the determined position of the occupant is more likely to result in injury to the occupant if the occupant protection device were to deploy.

2. The method of claim 1, wherein the algorithms are pattern recognition algorithms.

3. The method of claim 1, wherein the algorithms are neural networks.

4. The method of claim 1, wherein the step of acquiring data from at least one sensor comprises the step of arranging a plurality of sensors arranged in the vehicle, each of the sensors providing data relating to the occupancy state of the seat.

5. The method of claim 1, further comprising the step of selecting the at least one sensor from a group consisting of a camera, an ultrasonic sensor, a capacitive sensor or other electric or magnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor.

6. The method of claim 1, further comprising the step of selecting the at least one sensor from a group consisting of an electromagnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, an accelerometer and a heartbeat sensor for sensing a heartbeat of the occupant.

7. The method of claim 1, wherein the classification of the type of occupant and the size of the occupant is performed by a combination neural network created from a plurality of data sets, each of the data sets representing a different occupancy state of the seat and being formed from data from the at least one sensor while the seat is in that occupancy state.

8. The method of claim 1, further comprising the step of providing a previous determination of the position of the occupant to the algorithm for determining a current position of the occupant.

9. The method of claim 1, wherein the data from the at least one sensor is acquired periodically.

10. The method of claim 1, wherein adjustment of deployment of the occupant protection device when the occupant is classified as an empty seat or a rear-facing child seat comprises a depowered deployment, an oriented deployment or a late deployment.

11. The method of claim 1, further comprising the steps of:

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determining whether the acquired data is compatible with data for classification of the type or size of the occupant; and

when the acquired data is not compatible with the data for classification of the type or size of the occupant, rejecting the acquired data and acquiring new data.

12. A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component,

determining an occupancy state of the seat based on the acquired data;

periodically acquiring new data from the at least one sensor;

for each time new data is acquired, determining the occupancy state of the seat based on the acquired new data and the determined occupancy state from a preceding time; and

controlling the component based on the determined occupancy state of the seat.

13. The method of claim 12, wherein the step of acquiring data from at least one sensor comprises the step of arranging a plurality of sensors arranged in the vehicle, each of the sensors providing data relating to the occupancy state of the seat.

14. The method of claim 12, further comprising the step of selecting the at least one sensor from a group consisting of a camera, an ultrasonic sensor, a capacitive sensor or other electric or magnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor.

15. The method of claim 12, further comprising the step of selecting the at least one sensor from a group consisting of an electromagnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, an accelerometer and a heartbeat sensor for sensing a heartbeat of the occupant.

16. The method of claim 12, wherein the step of determining the occupancy state of the seat is performed using at least one pattern recognition algorithm.

17. The method of claim 12, wherein the step of determining the occupancy state of the seat is performed using a combination neural network.

18. A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component;

identifying the occupant based on the acquired data;

determining the position of the occupant based on the acquired data;

controlling the component based on at least one of the identification of the occupant and the determined position of the occupant;

periodically acquiring new data from the at least one sensor; and

for each time new data is acquired, identifying the occupant based on the acquired new data and an identification from a preceding time and determining the position of the occupant based on the acquired new data and then controlling the component based on at least

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one of the identification of the occupant and the determined position of the occupant.

19. The method of claim 18, wherein the step of determining the position of the occupant based on the acquired new data comprises the step of considering a determination of the position of the occupant from the preceding time.

20. The method of claim 18, wherein the step of acquiring data from at least one sensor comprises the step of arranging a plurality of sensors in the vehicle, each of the sensors providing data relating to the occupancy state of the seat.

21. The method of claim 20, wherein the step of identifying the occupant based on the acquired data comprises the step of using data from a first subset of the plurality of sensors and the step of determining the position of the occupant based on the acquired data comprises the step of using data from a second subset of the plurality of sensors different than the first subset.

22. The method of claim 18, further comprising the step of selecting the at least one sensor from a group consisting of a camera, an ultrasonic sensor, a capacitive sensor or other electric or magnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor.

23. The method of claim 18, further comprising the step of selecting the at least one sensor from a group consisting of an electric or magnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, an accelerometer and a heartbeat sensor for sensing a heartbeat of the occupant.

24. The method of claim 18, wherein the steps of identifying the occupant based on the acquired data and determining the position of the occupant based on the acquired data are performed using pattern recognition algorithms.

25. The method of claim 18, wherein the steps of identifying the occupant based on the acquired data and determining the position of the occupant based on the acquired data are performed using a combination neural network.

26. The method of claim 18, wherein the step of determining the position of the occupant comprises the step of inputting the acquired data into one of a plurality of algorithms selected based on the identification of the occupant, each of the algorithms being applicable for a specific identification of the occupant.

27. The method of claim 26, wherein the algorithms are pattern recognition algorithms.

28. The method of claim 26, wherein the algorithms are neural networks.

29. The method of claim 18, further comprising the step of classifying the size of the occupant, the step of determining the position of the occupant comprising the step of inputting the acquired data into one of a plurality of algorithms selected based on the size of the occupant, each of the algorithms being applicable for a specific size of occupant.

30. The method of claim 29, wherein the algorithms are pattern recognition algorithms.

31. The method of claim 29, wherein the algorithms are neural networks.

32. A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component;

identifying an occupant based on the acquired data;

determining the position of the occupant based on the acquired data;

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controlling the component based on at least one of the identification of the occupant and the determined position of the occupant;

periodically acquiring new data from the at least one sensor; and

for each time new data is acquired, identifying an occupant based on the acquired new data and determining the position of the occupant based on the acquired new data and a determination of the position of the occupant from a preceding time and then controlling the component based on at least one of the identification of the occupant and the determined position of the occupant.

33. The method of claim 32, wherein the step of identifying the occupant based on the acquired new data comprises the step of considering an identification of the occupant from the preceding time.

34. The method of claim 32, wherein the step of acquiring data from at least one sensor comprises the step of arranging a plurality of sensors arranged in the vehicle, each of the sensors providing data relating to the occupancy state of the seat.

35. The method of claim 34, wherein the step of identifying the occupant based on the acquired data comprises the step of using data from a first subset of the plurality of sensors and the step of determining the position of the occupant based on the acquired data comprises the step of using data from a second subset of the plurality of sensors different than the first subset.

36. The method of claim 32, further comprising the step of selecting the at least one sensor from a group consisting of a camera, an ultrasonic sensor, a capacitive sensor or other electric or magnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor.

37. The method of claim 32, further comprising the step of selecting the at least one sensor from a group consisting of an electric or magnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of heartbeat of the occupant.

38. The method of claim 32, wherein the steps of identifying the occupant based on the acquired data and determining the position of the occupant based on the acquired data are performed using pattern recognition algorithms.

39. The method of claim 32, wherein the steps of identifying the occupant based on the acquired data and determining the position of the occupant based on the acquired data are performed using a combination neural network.

40. The method of claim 32, wherein the step of determining the position of the occupant comprises the step of inputting the acquired data into one of a plurality of algorithms selected based on the identification of the occupant, each of the algorithms being applicable for a specific identification of the occupant.

41. The method of claim 40, wherein the algorithms are pattern recognition algorithms.

42. The method of claim 40, wherein the algorithms are neural networks.

43. The method of claim 32, further comprising the step of classifying the size of the occupant, the step of determining the position of the occupant comprising the step of inputting the acquired data into one of a plurality of algorithms selected based on the size of the occupant, each of the algorithms being applicable for a specific size of occupant.

44. The method of claim 43, wherein the algorithms are pattern recognition algorithms.

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45. The method of claim 43, wherein the algorithms are neural networks.

46. A method for controlling a component in a vehicle, comprising the steps of:

acquiring data from at least one sensor relating to an occupant of a seat interacting with or using the component;

identifying the occupant based on the acquired data;

when the occupant is identified as a child seat,

determining the orientation of the child seat based on the acquired data,

determining the position of the child seat by means of one of a plurality of algorithms selected based on the determined orientation of the child seat, each of the algorithms being applicable for a specific orientation of a child seat, and

controlling the component based on the determined position of the child seat; and

when the occupant is identified as other than a child seat, determining at least one of the size and position of the occupant, and

controlling the component based on the at least one of the size and position of the occupant.

47. The method of claim 46, wherein the step of acquiring data from at least one sensor comprises the step of arranging a plurality of sensors arranged in the vehicle, each of the sensors providing data relating to the occupancy state of the seat.

48. The method of claim 47, wherein the step of identifying the occupant based on the acquired data comprises the step of using data from a first subset of the plurality of sensors and the step of determining the orientation of the child seat based on the acquired data comprises the step of using data from a second subset of the plurality of sensors different than the first subset.

49. The method of claim 46, wherein the identification of the occupant is performed by a pattern recognition algorithm.

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50. The method of claim 46, wherein the determination of the orientation of the child seat is performed by a pattern recognition algorithm.

51. The method of claim 46, wherein the determination of the at least one of the size and position of the occupant when other than a child seat is performed by a pattern recognition algorithm.

52. The method of claim 46, wherein the algorithms are pattern recognition algorithms.

53. The method of claim 46, wherein the algorithms are neural networks.

54. The method of claim 46, further comprising the step of selecting the at least one sensor from a group consisting of a camera, an ultrasonic sensor, a capacitive sensor or other electric or magnetic field monitoring sensor, a weight or other morphological characteristic detecting sensor and a seat position sensor.

55. The method of claim 46, further comprising the step of selecting the at least one sensor from a group consisting of an electromagnetic wave sensor, an electric field sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a radar sensor, a weight distribution sensor, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, an accelerometer and a heartbeat sensor for sensing a heartbeat of the occupant.

56. The method of claim 1, wherein the identification of the occupant, the determination of the orientation of the child seat, the determination of the position of the child seat and the determination of the at least one of the size and position of the occupant when other than a child seat is performed by a combination neural network created from a plurality of data sets, each of the data sets representing a different occupancy state of the seat and being formed from data from the at least one sensor while the seat is in that occupancy state.

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